Volume 14 APRIL 1930 Number 4

BULLETIN
of the
American Association *of* Petroleum Geologists

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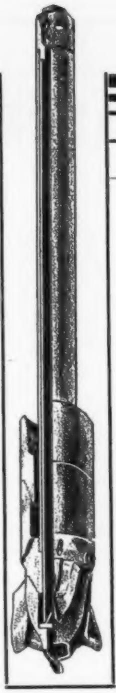

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The subscription price to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.
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Association Headquarters—504 Tulsa Building, East Fifth Street at Cincinnati Avenue, Tulsa, Oklahoma.

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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.
BOX 1852
TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Okla., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

MID-WEST PRINTING CO., TULSA, OKLA., U. S. A.

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APRIL 1930

McLURE SHALE OF THE COALINGA REGION, FRESNO AND KINGS COUNTIES, CALIFORNIA[1]

GERARD HENNY[2]
Oilfields, California

ABSTRACT

The McLure shale is a name given by the writer to the brown shale of the southern Coalinga region, previously termed Santa Margarita (?) shale on the geological maps of the U. S. Geological Survey. It is found, however, that this shale lies with an angular unconformity on Santa Margarita sandstone (Miocene), and that the Etchegoin (Pliocene) lies unconformably on the shale. Whether it is upper Miocene or lowest Pliocene in age has not been determined. In view of these recent observations, a new name for the shale is imperative.

The brown shale of the Coalinga region which was called Santa Margarita (?) by Arnold and Anderson[3] is present in the Devil's Den region and comprises Pyramid Hills, Chalk Buttes, and Tent Hills adjacent to McLure Valley. As the writer can prove that this shale is younger than the Santa Margarita (Miocene) sandstone underlying it and certainly older than the Etchegoin (Pliocene), it stands out as a unit, though its exact age is undetermined. He proposes, therefore, to

[1]Presented before the Pacific Section of the Association at the San Francisco meeting, November 21, 1929. Manuscript received by the editor, January 16, 1930. Publication of this paper was made possible by the consent of E. F. Davis, of the Shell Oil Company. The fossils in this area were determined by H. G. Schenck, A. J. Tieje, and Alex Clark. Mr. Schenck and Mr. Clark visited the different localities with the writer, who is indebted to them for their suggestions. Throughout this work the writer was ably assisted by P. W. Reinhart.

[2]Geologist, Shell Oil Company.

[3]Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull. 398* (1910).

give this shale a distinct name and suggests the name McLure shale. Other names such as Emigrant, Pyramid, and Avenal are no longer available. The name McLure shale is appropriate, as this formation borders McLure Valley on nearly all sides.

The type locality chosen for the McLure shale is a canyon crossing Tent Hills south of Avenal Creek near the west line of Sec. 6, T. 24 S., R. 17 E. A stratigraphic section of the shale is shown in Table I.

TABLE I

McLure Shale, Sec. 8, T. 24 S., R. 17 E.

	Thickness in Feet
Etchegoin (Pliocene)	
1. Dark brown clayey and silty shale apparently without micro-organisms	90
2. Hard siliceous brown shale with micro-organisms	320
3. Brown siliceous shale, softer and less resistant to erosion than shale No. 2. It contains limy concretions of dark gray color, the weathered surfaces of which are yellow. The top of this division is coarse silty shale. The base also is coarse silty shale containing semi-rounded pebbles of the Franciscan (Cretaceous) and some white shale containing micro-organisms. These pebbles are not more than ½ inch in diameter	390
Cretaceous	
Total	800

These same divisions in the McLure shale exist also on Reef Ridge, where the middle division is also more siliceous than the other part of the shale and forms a prominent feature. The upper division contains micro-organisms. The average thickness of the shale is about 800 feet. It overlies the Temblor (Miocene), the contact with which is well exposed in Zapota Canyon. The base of the McLure formation consists of about 30 feet of light gray coarse sandstone with concretions. At the contact with the Temblor, which forms an irregular surface, it contains rounded pebbles.

From Reef Ridge the McLure shale continues without interruption into Waltham Valley, where it is exposed on the southwest slope of the valley. Its average thickness here also is about 800 feet. The lower half of the shale in this region is siliceous and resistant to erosion. The upper half is clayey and less prominent topographically. Micro-organisms are found throughout the formation.

Pack and English[1] noticed, south of Sulphur Creek near the old Waltham School, 40 feet of sandstone at the base of the McLure shale. They also observed here that this basal McLure sandstone was overlying,

[1] R. W. Pack and W. A. English, "Geology and Oil Prospects of Waltham, Priest, Bitterwater, and Peach Tree Valleys, California," *U. S. Geol. Survey Bull. 581-D* (1914).

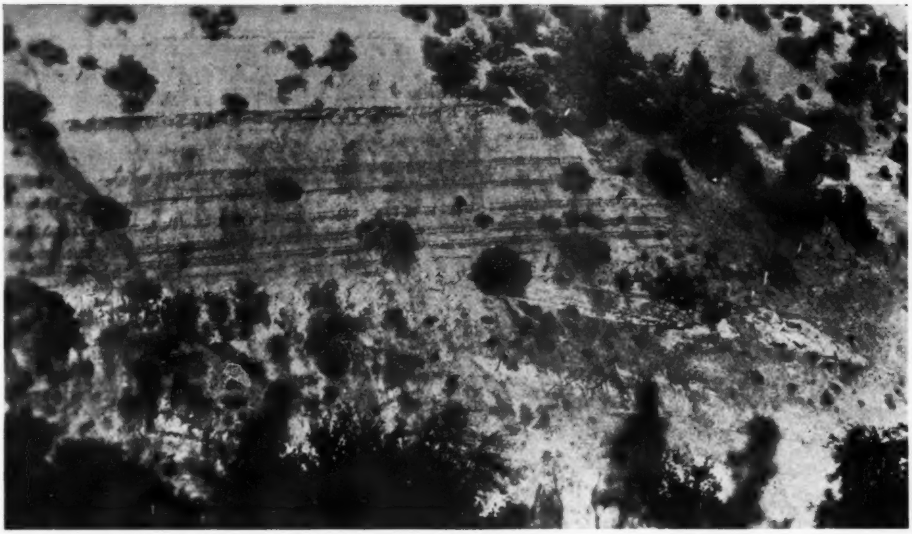


FIG. 1.—McLure sandstone unconformably overlying massive sandstone beds.

FIG. 2.—Angular unconformity of McLure shale with underlying Santa Margarita sandstone.

with an angular unconformity, massive sandstone beds to which they mistakenly gave a Temblor age (Fig. 1). Figure 2 also shows plainly an angular unconformity of the McLure shale with the underlying Santa Margarita sandstone. It is taken farther northwest in Sec. 7, T. 21 S., R. 13 E., in the first canyon south of Dogwood Creek, a western side canyon of Waltham Creek.

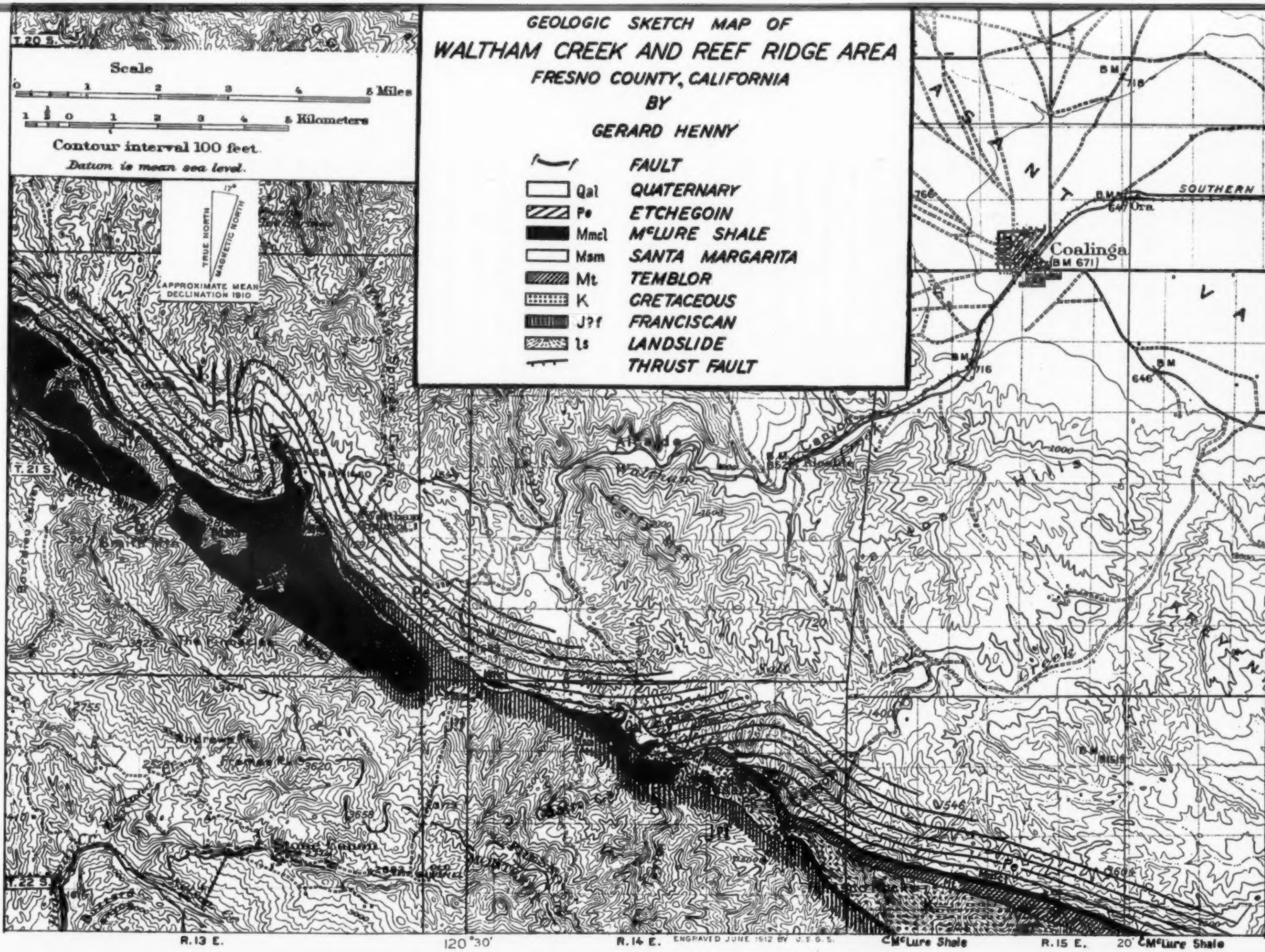
The sandstone unconformably underlying the McLure shale is of Santa Margarita age. Arnold and Anderson recognized this fact, but these authors did not observe the unconformity with the overlying McLure shale. For this reason they thought this shale also was of Santa Margarita age; therefore, they termed it Santa Margarita (?). The writer sent fossils from the Santa Margarita sandstone to A. J. Tieje and Bruce Clark. He visited some of the localities with H. G. Schenck and Alex Clark, and all these paleontologists agree that its age is definitely Santa Margarita.

The following fossils were collected here by Schenck, Alex Clark, and the writer.

Tamiosoma gregaria Conrad
Pecten estrellanus
Pecten cf. *crassicardo biformatis* Nomland
Pecten raymondi Clark
Thais carisaensis F. M. Anderson
Chione semiplicata
Solen perrini Clark
Calyptrea cf. *martini* Clark
Astrodapsis sp. indet., with prominent raised petals; not found below Santa Margarita

The sketch map (Fig. 3) shows approximately the general strike in the Etchegoin. The map is the result of field work on base airplane photographs. It shows plainly, as do the photographs, that an angular unconformity exists between the McLure shale and the Etchegoin in upper Jacalitos Canyon. The strike of the Etchegoin makes a very marked angle with the trend of the McLure shale in this particular place. Another proof of the unconformity between the Etchegoin and the McLure shale was noticed in upper Avenal Canyon northwest of McLure Valley, in Sec. 21, T. 23 S., R. 16 E. A patch of Etchegoin lies unconformably on the contact of the McLure shale with the Cretaceous.

All of the foregoing proves that the McLure shale, lying unconformably on Santa Margarita sandstone and overlain unconformably in turn by the Etchegoin, occupies a distinct place in the stratigraphic column. As to its age, the writer can state that the shale is younger than the Santa


GEOLOGIC SKETCH MAP OF
WALTHAM CREEK AND REEF RIDGE AREA
FRESNO COUNTY, CALIFORNIA
BY
GERARD HENNY
FAULT
Qal QUATERNARY
Pe ETCHEGOIN
Mmcl McLURE SHALE
Msm SANTA MARGARITA
Mt TEMBLOR
K CRETACEOUS
J?f FRANCISCAN
ls LANDSLIDE
THRUST FAULT
Scale
5 Miles
5 Kilometers
Contour interval 100 feet.
Datum is mean sea level.
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION 1910
Coalinga
BM 671
SOUTHERN
T. 20 S.
T. 21 S.
T. 22 S.
R. 13 E.
120°30'
R. 14 E.
ENGRAVED JUNE 1912 BY U.S.G.S.
McLure Shale
R. 15 E.
20'
McLure Shale
FIG. 3

Margarita sandstone and older than the Etchegoin. A more exact statement of its age can not yet be made because it contains only microorganisms and no other fossils.

As was stated previously, the McLure shale is present on the southwest slope of upper Waltham Valley. This shale does not exist, however, on the northeast slope. Here the Etchegoin is in direct contact with the Cretaceous of Juniper Ridge. Juniper Ridge apparently consists of a monoclinal Cretaceous series, dipping steeply 40°-70° NE., and the Etchegoin is folded as an anticline over this Cretaceous series. Patches of Etchegoin are still present on the highest parts of this ridge north of Alcalde Canyon. On the west side of Pleasant Valley, west of Coalinga, the Etchegoin completely overlaps the Santa Margarita and the Eocene south of the San Joaquin coal mine. From this place southward it continues directly in contact with the Cretaceous. It is true that Arnold and Anderson designated all this Etchegoin sandstone as Vaqueros, but the writer found here typical Jacalitos (lower Etchegoin, Pliocene) fossils, among which *Thais kettlemanensis* Arnold is one of the most characteristic. Seemingly, the McLure shale is not present in Pleasant Valley, and is buried under the Etchegoin on the northeast side of upper Waltham Valley.

As shown in Figure 2, an angular unconformity exists between the McLure shale and the underlying Santa Margarita sandstone.

South of Busane Peak, which is near the conjunction of Jasper and Jacalitos canyons and south of the mapped area, McLure shale builds up Mustang Peak. Fossiliferous Santa Margarita sandstone forms the base of this shale and is situated on the contact of the Cretaceous and the Franciscan. As this Mustang Peak is on the Monterey-Fresno county line, on the highest ridge forming the divide between the Cholame-Parkfield area and San Joaquin Valley, both the Santa Margarita and the McLure shale show a tremendous overlap across all the older formations. Also this fact proves that these formations, in spite of the unconformity existing between them, appear near together.

The McLure shale forms one continuous band from upper Waltham Canyon along Reef Ridge toward McLure Valley and the Devil's Den area. Seemingly no Santa Margarita sandstone is present at the base of the shale along Reef Ridge and the Devil's Den area. In McLure Valley at the southern end of Tent Hills, composed of McLure shale, some sandstone appears between this shale and the Cretaceous. As it contains many *Phacoides annulata* Conrad, it is probably Santa Margarita in age.

In the Devil's Den area the McLure shale is situated unconformably on the Monterey shale, and no Santa Margarita is present between the two formations. It is true that the McLure shale is more siliceous than the Monterey shale, but farther south both formations may have a more similar facies. It may, therefore, be difficult to find the exact contact between them. It is also possible that some McLure shale is present in the Temblor Range.

In the Parkfield area, Walter English indicates Santa Margarita (?) shale at the north edge of Cholame Valley.[1] If this is really McLure shale, it continues directly along the northeast border of Cholame Valley into the Temblor Range. This shale, however, lies directly on typical fossiliferous Temblor sandstone.

The thickness of the McLure shale in upper Waltham Valley and on Reef Ridge is approximately 800 feet. In the north dome of the Kettleman Hills it seems to have a thickness of more than 1,000 feet in the wells. In the south dome of the Kettleman Hills field it is probable that the McLure shale lies over the Monterey shale, as this area is in the vicinity of the Devil's Den area where the same condition exists.

In the Temblor Range, undoubtedly most of the brown shale is Monterey in age. In Cedar Canyon, a side canyon south of Bitterwater Creek, it can be seen that a Temblor reef-bed farther southeast forms the base of the Monterey shale. Toward the northwest near the south line of T. 21 S., R. 18 E., this begins to appear gradually in the Monterey shale. This fact shows a lateral change in facies of the Temblor sandstone below this reef-bed as it merges into the Monterey shale.

Some McLure shale possibly exists on the southwest flank of the Temblor Range along the Carrizo Plains. Overthrusts toward the southwest appear here in the shale, and the change of the shale into the Etchegoin sandstone is so gradual that it is very difficult to trace a contact between the two formations. It is, of course, a strange fact that in this region no unconformity exists between the McLure shale and the Etchegoin, such as is determined in the Coalinga district. North of Coalinga, between Oilfields and Panoche Creek, the fossiliferous Santa Margarita sandstone and shales form one continuous series with the Etchegoin along the border of San Joaquin Valley. Both formations appear lithologically the same and no distinct contact between the two can be found. These Santa Margarita and Etchegoin series lie with an angular

[1] Walter A. English, "Geology and Oil Prospects of the Salinas Valley-Parkfield Area, California," *U. S. Geol. Survey Bull. 691-H* (1918).

unconformity on the Big Blue, which is probably of Temblor (Miocene) age.

The Waltham Creek and Reef Ridge regions show complicated structural features. This area is near the San Andreas fault and is marked by the existence of steep folds parallel with this fault. Between the head of Jacalitos Creek and the old Waltham School, the great mass of the Franciscan existing between the Parkfield area and the upper Jacalitos Creek continues as a narrow streak along the border of Waltham Valley. This condition is due to the existence of a steep anticline in the McLure shale. Toward the northwest this anticline goes over into an overthrust fault, which causes the Santa Margarita, underlying the McLure shale, to lie unconformably on vertical Etchegoin beds. Some lenses of the Franciscan appear along the fault plane. On the northwest in the Etchegoin the fault does not seem to be present.

Southeast of this locality, on the southwest side of Jacalitos Canyon near the mouth of Taylor Canyon, some Cretaceous appears in the middle of the McLure shale, showing that the same anticline probably still persists in this direction. The shale of the north flank of the anticline continues southeast along the bed of Jacalitos Creek and forms the northeast border of Reef Ridge. The shale of the southwest flank of the anticline appears in the middle of the Cretaceous which underlies the northwest end of the Temblor of Reef Ridge. Some sandstone in contact with this lens of McLure shale near Taylor Canyon may be Santa Margarita in age.

On the southeast, no brown shale could be detected between this locality and Jasper Canyon, but on the east slope of this canyon the McLure shale appears again between the Cretaceous and the Franciscan and can be followed for about 3 miles. The presence of this McLure shale southwest of Reef Ridge shows that in this region the structural features of the McLure shale are very complicated.

SANDSTONE DIKES AS CONDUITS FOR OIL MIGRATION THROUGH SHALES[1]

OLAF P. JENKINS[2]
San Francisco, California

ABSTRACT

The Kreyenhagen shale of Coalinga and the older Moreno shale contain many sandstone dikes. An Eocene sandstone lies between these two formations, and oil accumulating in this sandstone from the shale beneath could be transferred to the Miocene sandstone above through sandstone dike conduits in the Kreyenhagen shale.

Nothing is more strikingly peculiar in the foothill belt on the western side of the San Joaquin Valley, California, than the presence of many clastic dikes of sandstone which ramify through the great masses of diatomaceous shale of that region. The Kreyenhagen shale, in many places, contains great numbers of these irregular branching bodies of sand, some of them soft, others consolidated, and some hard. Their presence is considered a characteristic feature of the formation. The dikes range in size from a few inches to more than 60 feet in thickness. At some places they cut across the beds and at other places follow between the strata, forming sills. The Moreno (Cretaceous) shale also contains many such dikes, and, in places, dikes are found in the diatomaceous shales of the lower part of the Miocene (Fig. 1).

In explanation of the origin of the sandstone dikes in the Kreyenhagen shale, Robert Anderson and R. W. Pack[3] stated that the dikes

> may have been intruded into fractures in the shale by oil and gas under pressure, and their presence would thus be an indication that oil or gas once existed in these beds.

The writer believes, however, that the condition indicates that oil and gas once existed in the *underlying* beds.

[1]Read before the Pacific Section of the Association, at the San Francisco meeting, November 22, 1929. Manuscript received by the editor, January 16, 1930. Published by permission of the state mineralogist of California. This paper represents a chapter from a longer report by the writer, on the problem of the Kreyenhagen shale, to be published by the California State Division of Mines.

[2]Chief geologist, Geologic Branch, California State Division of Mines.

[3]Robert Anderson and R. W. Pack, "Geology and Oil Resources of the San Joaquin Valley, North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), p. 133.

FIG. 1.—Small sandstone dike cutting through the Kreyenhagen shale, on Panoche Pass road, 40 miles northwest of Coalinga.

An early paper by Diller[1] on sandstone dikes occurring at the forks of Cottonwood Creek on the northwestern border of the Sacramento Valley in California, is especially interesting. He shows that the dikes intrude Cretaceous shales, that they lie in parallel position, and that some of them are banded parallel with their sides.

Newsom[2] describes in a very thorough manner many sandstone dikes in California. On Graves Creek, near Asuncion, San Luis Obispo County, sandstone dikes were intruded from below, and have bent the intruded shales upward. He says:

> The dikes occur near the axis of a low synclinal fold, where former conditions were probably favorable to great hydrostatic pressure.

The bituminous sandstone dikes of Santa Cruz are clearly shown by Newsom to be connected with a bituminous sandstone bed underlying diatomaceous shale. He was evidently impressed with the fact that oil had escaped through the sandstone dikes, but he does not mention the possibility of migration of oil to another reservoir. In regard to this subject he makes the following statement.

> The importance that may attach to such intrusions, which doubtless occur in other districts underlain by oil sands, is therefore apparent. Should

[1] J. S. Diller, "Sandstone Dikes," *Bull. Geol. Soc. Amer.*, Vol. 1 (1889), pp. 411-42, Pls. 6-8.

[2] J. F. Newsom, "Clastic Dikes," *Bull. Geol. Soc. Amer.*, Vol. 14 (1903), pp. 227-68, Pls. 21-31. (Quotations, pp. 234 and 252.)

sand intrusions occur near the crests of anticlinal folds, in which the hydrostatic pressure is not sufficient to force the oil all out from below, the sands of the intrusions might then be oil bearing and also lead downward to the underlying oil sands, thus forming an important source of oil supply. When, however, the intrusions are large, when they have low outlets to the surface and occur near the lower edge of the oil reservoir in a region of low hydrostatic pressure (or gas pressure from above), or when they occur at the upper edge of the oil reservoir in a region of high hydrostatic pressure, they are in a position to have completely drained the underlying beds of their oil.

These bituminous sandstone dikes were again described in the Santa Cruz folio[1] and the conclusion was reached that

former oil-bearing sands were forced into joints in the shale and that the residues from the oil entrapped......are still found in the dikes. The larger crevices probably formed the avenues of escape for the petroleum......and afterwards for the water of the underlying sands.

One dike, 8 miles northwest of Santa Cruz, has "an exposed width of 600 feet along the sea cliff" and extends "one-fourth of a mile inland."

Clark and Woodford[2] suggest that certain porous white sandstones interbedded in the Meganos formation near its type locality in the region of Mount Diablo, are injected sills rather than beds.

Meek[3] shows that the material of a certain sandstone dike, located east of Newport Beach, Orange County, California, "corresponds with the underlying Miocene sand rather than the overlying younger formation." He thinks that material probably filled an earthquake crack. Oil and tar impregnate the underlying Miocene sand, the dike, and the overlying Pleistocene sediments adjacent to the dike, which penetrates only the intervening shale. Though he does not directly say so, he has thus proved that the dike acted as a conduit for oil migration. He considers that the dike is older than the Pleistocene, but that the passage of oil through it occurred since the upper beds were deposited. This is based on (1) the "lack of dilution of the green hornblende assemblage in the upper beds by the accession of hornblende free sand from the dike," and (2) the fact that *Pholas* borings near the dike indicate that oil could not have been flowing from this injected body at the time these animals

[1] J. C. Branner, J. F. Newsom, and Ralph Arnold, "Santa Cruz Quadrangle," *U. S. Geol. Survey Geologic Atlas Folio 163* (1909), p. 9.

[2] Bruce L. Clark and A. O. Woodford, "The Geology and Paleontology of the Type Section of the Meganos Formation (Lower Middle Eocene) of California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 17 (1927), pp. 63-144.

[3] Charles E. Meek, "Genesis of a Sandstone Dyke as Indicated by Heavy Minerals," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 (1928), pp. 271-77.

were living, for an oil seepage would keep away such life. The writer questions this interpretation and suggests that both injection and oil migration happened since the deposition of the Pleistocene beds.

Whatever is their origin, or whatever they may indicate concerning the presence and later the escape of oil and gas, the dikes stand in a position (in many places) in which they could readily be used as natural conduits for oil in its migration from one horizon to another. For example, oil could thus migrate from the Moreno shale, in the Coalinga district, through these devious passages, to the upper formations—even into the great reservoir sandstones of the Miocene, lying at a much higher stratigraphic position. Perhaps this is the way the great deposit of high-gravity oil came to be accumulated in the Miocene oil sands of the recently discovered Kettleman field, near Coalinga. This would provide a mode of accumulation for a series of oil reservoirs above an oil-generating bed somewhat similar to the series Mills[1] describes in his experiments on the "relations of texture and bedding to movements of oil and water through sands."

Inasmuch as the sands of the dikes are evidently more pervious than the shales through which the dikes have been intruded, the dikes should be comparatively good conduits for oil. Their size, extent, and number are sufficient to provide ample means for oil to migrate through them. In many places the sandstones of these dikes show that they once contained oil. One example of such an oil-sand dike is exposed near the crest of the anticlinal structure in Oil Canyon, north of Coalinga (Fig. 2). The dikes, however, are not confined to the crest of anticlines; many are found well down on the flanks of such structures.

The dikes undoubtedly have a sandstone bed as their source, and, in many places, reach other sandstone beds of another horizon. In one locality, northeast of New Idria in the Vallecitos, a sandstone bed in the center of the Kreyenhagen shale has dikes of sandstone forming apophyses reaching out from it like arms. In the same vicinity, in an exposure near the road crossing San Carlos Creek, an angular unconformity is exhibited between the tilted beds of the Kreyenhagen shale and the overlying coarse beds of the Miocene, and, lying between shale beds, are sandstone sills—not beds which were deposited with the shale, but intruded bodies of sandstone, for the most part in a position parallel with the bedding of the formation, though in places they cut across the strata. These sills extend up to the unconformable contact.

[1]Van A. Mills, "Relations of Texture and Bedding to Movements of Oil and Water Through Sands," *Econ. Geol.*, Vol. 16 (1921), pp. 124-41.

FIG. 2.—Petroliferous sandstone dike, cutting the upper white shales of the Kreyenhagen on the west flank of the Coalinga anticline, near its crest, in Oil Canyon, 9 miles north of Coalinga.

Situated above them, and within the interstices of the overlying coarse conglomeratic sandstones of the Miocene, are accumulations of brea, cementing some of the Miocene gravels, and showing clearly that petroleum had previously been deposited in this overlying porous material. Evidently the oil originally migrated upward along the sandstone dike courses to the conglomerate layer just above the contact (Fig. 3).

The sands of many of the dikes in the Kreyenhagen resemble lithologically the sandstones of the Eocene (known as Tejon or Domengine). This sandstone horizon is commonly found to contain oil seeps. Unless the oil has migrated downward from the overlying Kreyenhagen shale, it seems that the Eocene sandstone has been supplied with oil from a source below, probably from the underlying petroliferous Moreno shale by way of sandstone-dike arteries penetrating the Moreno. The Miocene sandstones, overlying the Kreyenhagen shale, were, in turn, supplied with oil from the Eocene reservoir by way of sandstone dikes, extending through the Kreyenhagen shale on their course from one

FIG. 3.—Exposure on stream bank, showing unconformity between the Kreyenhagen brown shales below and the Miocene sandstones above. The white layers in the shale formation are thin sills of sandstone, which extend to the contact. Above are accumulations of brea in places cementing the coarser Miocene sands, showing clearly how oil has migrated up the sandstone dike channels and up the dipping beds of shale to the porous reservoir above. Location: southeast end of the Vallecitos, on the road to Idria, San Benito County.

sandstone body to another. The oil of the lower part of the Kreyenhagen shale undoubtedly also entered the sandstone dikes and contributed to the general supply migrating through these dikes.

In case an oil-bearing sandstone dike ended blindly in impervious shale, the contained oil might readily be entrapped. This condition might thus give local production to isolated wells. It seems more probable, however, in view of the many dikes present, that in most places the oil would eventually find its way through the body of shale to the upper sandstone beds. Undoubtedly the dikes followed joints and fracture planes, probably enlarging them. The pressure originally required to form the dikes, whether it was of hydrostatic nature or caused by gas accumulations, probably caused the dikes to be injected through the more impervious shale to upper layers of sandstones, where the pressure was released and the injected fluids were allowed to disperse freely in the more porous material. The fluids must have acted as lubricants to the injected materials.

The rôle played by sandstone dikes in the transference of oil from one formation to another seems to the writer to be of considerable economic importance, especially as the Cretaceous shale may prove to be the source

for such an oil field as Kettleman Hills. If, therefore, the Cretaceous shales prove to be an important source of oil, why should not the overlying Eocene sandstones be productive in some areas?

The explanation of the greater number of sandstone dikes in the Kreyenhagen and the Moreno shales than in most of the other deposits, is probably related to the mode of formation of the dikes. They were injected, undoubtedly, under pressure, and as soon as this pressure was released, their formation ceased. If we assume that gas and liquids under pressure caused the injection of the sand, we could not expect these materials to initiate the formation of dikes within a large body of sandstone where the gas and fluids could be disseminated laterally, but with a sufficient pressure in a more confining formation (such as the Domengine sandstone, which is limited to a few hundred feet in thickness), injections might be made into an overlying impervious shale. Cracks previously formed in overlying shales were used, re-opened, and material forced through them. As soon as the injections reached a larger and more pervious series of beds, the pressure was equalized and the dikes terminated.

If, however, we assume that diastrophism caused the dikes to be formed, the chances are that the heat involved generated gas from the petroliferous beds and this gas added just so much more pressure and provided lubrication for sand flowage. After the dikes were used as oil and gas conduits some of them were probably flushed by water, and later hardened by precipitated minerals.

If an oil-generating series of shale was overlain by a thick series of pervious sandstones, the oil might be able to migrate directly into the sandstones. If, however, a series of relatively impervious shales intervened between the oil-generating beds and the pervious sandstones, the oil and gas in the petroliferous beds would be pent up in such a manner that escape by means of injections of dikes would be likely to follow.

An example of such an overlying series of impervious shales resting upon the oil-generating series, and thus producing pressure-confinement in a sand bed charged with oil and gas, is found in the lower petroliferous series of the Kreyenhagen shales. These are overlain by more shales, which are not very petroliferous. They are white and very fissile. Following Tolman's biogenetic theory,[1] they should hardly be classed as an oil-generating series. Overlying the Moreno petroliferous shales are clay shales of the Eocene which seemingly are not petroliferous, and which

[1]C. F. Tolman, "Biogenesis of Hydrocarbons by Diatoms," *Econ. Geol.*, Vol. 22 (1927), pp. 454-74.

would confine the lower oil-bearing series. Furthermore, the Domengine sandstone, lying between those shales and the Kreyenhagen, is limited in thickness and represents the confined reservoir for oil accumulated from the lower shales, transported to this bed through sandstone-dike conduits.

The source of the sand in a particular series of dikes may be determined petrographically. So far, this work has not been done in the Coalinga district. Sandstone beds intercalated with the shale may represent the source material, but in many places it is probable that the Eocene sandstone supplied the material for the dikes.

The writer has previously demonstrated the mechanics[1] of a certain type of clastic dike injection by means of a simple laboratory experiment, showing why a banded structure (longitudinal with the bodies) is found in some clastic dikes. In this experiment, varicolored layers of plastic clay were compressed over two wooden blocks separated by a narrow crack. The result was that all the layers were injected in a double form within the crack, causing the original layers, though very thinly compressed, to form in bands, parallel with the walls of the crack. This may explain the peculiar structural form of one dike described by English.[2] He says that it "shows bedding and was evidently forced through the shales as a rigid mass during the folding of the beds." The writer is inclined to believe, however, that it was injected in a plastic condition. This sandstone dike, and others which English describes, occur in the Miocene shales, in the lower part of the section in the foothill region between McKittrick and Devil's Den. One of the other dikes he describes is 100 feet wide.

Most of the sandstone dikes of this region show no bedding. One large dike on Respini Creek, on the coast northwest of Santa Cruz, however, shows a peculiar horizontal stratification in part of the dike, although the other part is formed of vertical columns. The horizontal layers constitute a peculiar feature which is probably the result of a subterranean flowage (Fig. 4).

The age of the sandstone dikes must be younger than the Miocene. Probably the dikes were formed during the general deformation of the sediments, when oil and gas within the rocks were probably put under very great pressure, at a time when faults and fractures were developing.

[1] Olaf P. Jenkins, "Mechanics of Clastic Dike Intrusion," *Eng. and Min. Jour.-Press*, July 4, 1925.

[2] Walter English, "Geology and Petroleum Resources of Northwestern Kern County, California," *U. S. Geol. Survey Bull. 721* (1921), pp. 25-26.

Gas probably was generated as a result of the heat that accompanied compression. The lubricated sands were then injected into cracks. The time of the general folding of the formations probably extended through a long period, but as the disturbance affected the late Tertiary and even the Quaternary, as well as the older rocks, some of the move-

FIG. 4.—Near view of a part of a large sandstone dike which intrudes Monterey shale and is exposed on the sea cliff near Respini Creek, 8 miles northwest of Santa Cruz. Two types of texture are exhibited, vertical bands of the hard injected dikes, and horizontal laminae of softer sands. The latter are considered to be the result of subterranean flowage, which occurred after the more forceful injections, as a backflow from the dikes. The laminated sands carry angular blocks of the white shale.

ments must have occurred during a comparatively recent time. It may be inferred, therefore, that the age of the dikes is late Tertiary or Quaternary.

It must not, however, be inferred that the origin of all clastic dikes is considered to be associated with oil and gas. That most of them have been injected seems evident. This would require a certain pressure, and the material of the dikes would, no doubt, be more readily injected if the sands were lubricated. Lubrication by means of hydrocarbons, and pressure developed through the generation of gas and through diastrophism acting either directly or indirectly, seem to be the most probable causes of injection in the particular area described.

A sandstone dike of the nature herein described may thus have been formed in much the same way as the peculiar type of dike associated

with igneous rocks and described by Daly[1] as a *diatreme*, a vent opened by gas explosion and filled with fragmental materials. The gas forming the diatreme would be, of course, magmatic and not of organic or sedimentary origin.

Clastic dikes of different sorts have been found elsewhere in the world, occurring under various conditions. For example, dust and sand dikes occur in alluvial gravels of Walla Walla, Washington;[2] limestone dikes are found in tuff in the Santa Cruz quadrangle;[3] conglomerate and sandstone dikes intrude granite of Colorado.[4] There are many other references[5-15] to these injected clastic bodies.

The origin of each dike depends upon particular circumstances. The source of the materials of many clastic dikes has been shown to be from below, but in some places it is undoubtedly from above the present

[1]R. A. Daly, *Igneous Rocks and their Origin* (1914), pp. 251-53, 294, and 300.

[2]Olaf P. Jenkins, "Clastic Dikes of Eastern Washington and Their Geologic Significance," *Amer. Jour. Sci.*, Vol. 10, 5th ser. (1925), pp. 234-46.

[3]*Ibid.*, p. 8.

[4]W. Cross, "Intrusive Sandstone Dikes in Granite," *Bull. Geol. Soc. Amer.*, Vol. 5 (1894), pp. 225-30.

[5]Robert Hay, "Sandstone Dikes in Northwestern Nebraska," *Bull. Geol. Soc. Amer.*, Vol. 3 (1892), pp. 50-55.

[6]R. D. Irving, "The Copper Bearing Rocks of Lake Superior," *U. S. Geol. Survey Monograph 5* (1893), pp. 140, 292-93.

[7]J. S. Diller, "Tertiary Revolution in the Topography of the Pacific Coast," *U. S. Geol. Survey 14th Ann. Rept.*, Pt. 2 (1894), Pl. 47, p. 424.

[8]A. P. Pavlow, "Dikes of Oligocene Sandstone in Russia," *Geol. Mag.*, Vol. 3 (February, 1896), pp. 49-53.

[9]F. L. Ransome, "A Peculiar Clastic Dike near Ouray, Colorado, and Its Associated Deposit of Silver Ore," *Trans. Amer. Inst. Min. Eng.*, Vol. 30 (1900), pp. 227-36.

[10]E. Greeley, "Sandstone Pipes," etc., *Geol. Mag.* (January, 1900), pp. 20-24.

[11]George H. Eldridge, "The Asphalt and Bituminous Rock Deposits of the United States," *U. S. Geol. Survey 22nd Ann. Rept.*, Pt. 1 (1900-01), pp. 209-464, especially pp. 386-407. Bituminous dikes of different sorts are described in this paper.

[12]S. W. McCallie, "Sandstone Dikes near Columbus, Georgia," *Amer. Geol.*, Vol. 32 (1903), pp. 199-202.

[13]Ralph Arnold and Harold Hannibal, "The Marine Tertiary Stratigraphy of the Pacific Coast of America," *Proc. Amer. Phil. Soc.*, Vol. 52, No. 212 (November-December, 1913), Pl. 45.

[14]J. E. Spur, *The Ore Magmas*, Vol. 2 (1923), Chap. 19, "The Sand or Breccia Dike," pp. 843-57.

[15]M. R. Campbell, "Conglomerate Dikes in Southern Arizona," *Amer. Geol.*, Vol. 33 (1924), pp. 135-38.

position of the dikes. Intensive pressure (hydrostatic, diastrophic, or otherwise) within the formation may be the cause of injection in one place; in another, earthquake cracks at the surface might allow dikes to be formed through surface inflow. Materials may be dropped into the cracks. Mud craters give evidence that the clastic particles are welling up from below. Whatever is their origin, the fact remains that many of the sandstone dikes and sills of the California oil districts are conveniently located to act as conduits for oil migration. The result of this migration is probably of great economic significance, but has not hitherto been given much consideration.

PROPOSAL FOR CHANGE OF NAME

In response to numerous suggestions made to the writer that the name *dike* is unsuitable to clastic dikes, because of its ordinary connotation of igneous origin, he tentatively suggests such a name as *intruclast* to combine the ideas of intrusion and clasticity.

SURFACE AND SUBSURFACE STRUCTURE OF THE TRI-COUNTY OIL FIELD OF SOUTHWESTERN INDIANA[1]

J. M. WANENMACHER[2] and W. B. GEALY[3]
New York, New York, and Pittsburgh, Pennsylvania

ABSTRACT

A previous investigator concluded that surface structure gives no clue to subsurface structure in this field. The writers believe that subsurface structure is reflected by surface structure in a general way. Recent developments have made the latter conclusion possible.

INTRODUCTION

Late in the summer of 1929 the writers were instructed to investigate the relation of surface to subsurface structure in one of the producing fields of southwestern Indiana. The Tri-County field was selected because it is a comparatively recent development and drilling records were accessible. The field seemed to have no definite name, though some members of the local oil fraternity referred to it as the Oakland City Extension, because of its proximity to the old, well known Oakland City field. Others called it the Somerville pool. Later it was discovered that Esarey had named it the Tri-County field. This name is appropriate, as the field is in both Gibson and Pike counties and near the border of Warrick County.

The reader is referred to the article by Esarey[4] for a comprehensive discussion of the history, stratigraphy, and general information concerning the field. Later development has furnished additional data from which the conclusion is reached that subsurface structure has a general positive relation to surface structure, whereas Esarey, from the data then available, concluded that no such relation exists.

Two weeks in late August and early September of 1929 were consumed in field work. Plane-table and alidade traverse was carried

[1]Read by title before the Association at the New Orleans Meeting, March 20, 1930. Manuscript received by the editor, January 23, 1930.

[2]Geologic department, Gulf Oil Corporation, Room 717, 21 State Street.

[3]Geologic department, Gulf Oil Corporation, Box 1214.

[4]R. E. Esarey, *Bull. Amer. Assoc. Petrol Geol.*, Vol. 11 (1927), pp. 601-10. Reprinted in *Structure of Typical American Oil Fields*, Vol. 1 (Amer. Assoc. Petrol. Geol., 1929), pp. 23-34.

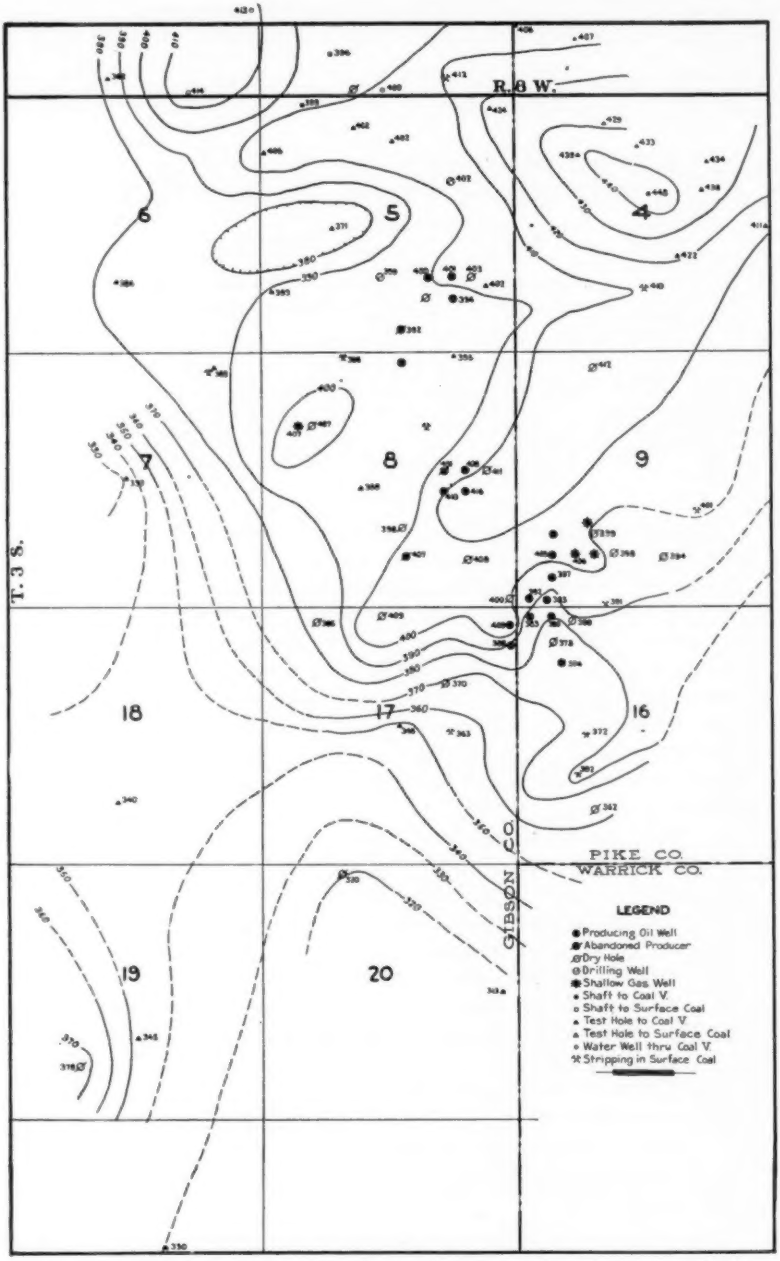


FIG. 1.—The key horizon is Coal V. Contour interval, 10 feet. Datum is sea-level.

through the area. All elevations are believed to be correct within 1 foot, except for abandoned tests where the exact well sites could not be determined. The error in such elevations may be as much as 4 feet.

Surface rocks are well concealed by soil; only a few outcrops are found. However, there are many coal workings and the surface rocks have been penetrated by coal tests, water wells, shallow gas wells, and oil tests. The records of most of these were available.

ACKNOWLEDGMENTS

Thanks are due to W. W. Rogers, a local operator, who kindly furnished records of oil tests, coal tests, and shallow gas wells; to Alfred Carter, Atlee Carter, and Milton Duncan for records of coal tests and water wells; and to K. C. Heald for criticism of the manuscript.

STRATIGRAPHY

Surface rocks are of Allegheny age. The deeper borings have penetrated Pottsville and late Mississippian strata. A study of well logs shows that even in this small area the strata exhibit pronounced thickening, thinning, and lensing; therefore, marked variations in stratigraphic intervals.

Coal V, though it does not crop out, was chosen as the most satisfactory horizon for mapping the surface structure. It has been penetrated by all the oil tests, the shallow gas wells, several water wells, and tests for this coal. It is persistent. Because of the presence close above it of a stratum of iron and lime carbonates so hard that it is logged as "steel band," it is missed by few drillers familiar with the region. A surface coal locally called Coal VI, but probably Coal VII of the Indiana State coal report,[1] is 90 feet above Coal V. It is underlain by a gray limestone member, which ordinarily consists of two thin beds separated by a shale break. At places these thin lime beds merge to form a single limestone 10-12 feet thick. The top of this limestone is about 80 feet above Coal V. The intervals between these horizons and Coal V differ locally; consequently, one must exercise caution in using them.

The top of the Big lime was first chosen as the horizon for mapping subsurface structure. It is near the oil sands. As it is used as a casing seat, it is everywhere recognized and usually accurately measured. However, the interval between the top of the Big lime and the top of the productive sand ranges from 40 to 60 feet. Consequently, structure

[1] G. H. Ashley, "The Coal Deposits of Indiana," *Dept. of Geol. and Nat. Resources of Indiana 23d Ann. Rept.* (1898), p. 85.

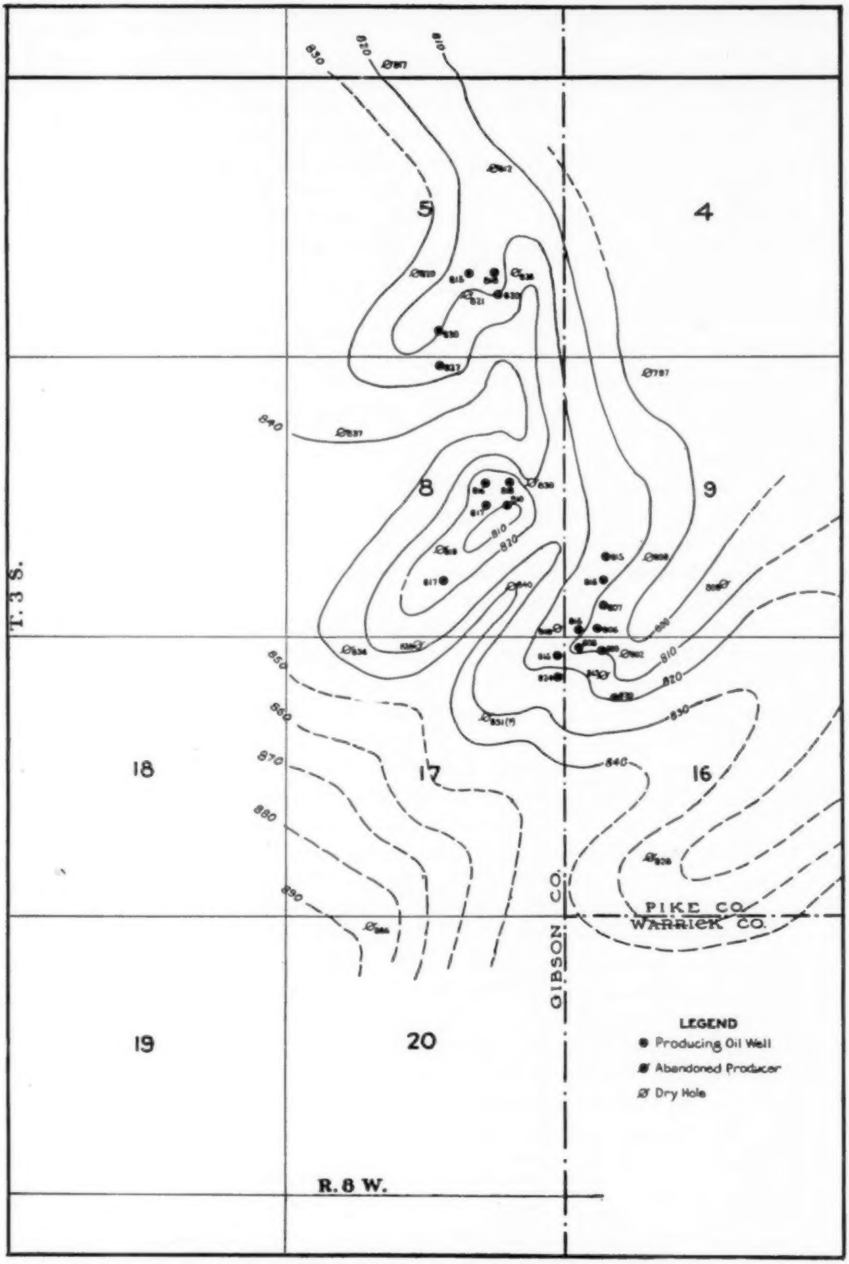


FIG. 2.—The key horizon is the Oakland City sand. Figures show depth below sea-level. Contour interval, 10 feet.

shown on the top of the Big lime differs noticeably from structure as mapped on the Oakland City sand. As it is the structure of the Oakland City sand which has influenced accumulation therein, this horizon was finally used to portray subsurface structure.

PRODUCING HORIZONS

Oil production is at present entirely from the Oakland City sand, which ranges from almost nothing to 50 feet in thickness. Shale partings occur within it. It is "spotty," that is, its productivity varies markedly within short distances, and in this respect it resembles certain Chester sands of western Kentucky. Beneath this sand and separated from it by 20-60 feet of alternating brown limestones and shales is the Brown oil sand. It has been tested in a few wells; in one it yielded light production. A well in the western part of the area encountered a thick Pottsville sand stained with oil, though unproductive.

STRUCTURE

Surface structure mapped on Coal V and subsurface structure mapped on the Oakland City sand are shown in Figure 1 and Figure 2. The regional dip of both is southwest. The subsurface structure in the general productive area consists of sharp southwestward-plunging noses. Three such noses are definitely known and a fourth may be present, as shown by broken contours. These are reflected by a broad, gentle terrace in the surface structure. Toward the south is a pronounced drop both in surface and subsurface beds. A similar drop is present in the surface structure west of the productive area, but the attitude of the subsurface beds is not known.

CONCLUSION

If a similar relation between surface and subsurface structure exists in this general area—and it is logical to assume that this is true—much unfavorable territory may be eliminated by confining exploration to areas of broad surface "highs." It is important, however, to emphasize the fact that structure is not the only factor which has influenced the accumulation of oil in this area. Irregular distribution of the sand has had some effect upon accumulation, but it can not complete the explanation because some of the dry holes encountered sand. It seems probable that specific characteristics of the sand, including differential cementation, have been effective in limiting the distribution of the oil.

DISCUSSION

R. E. Esarey, Chicago, Illinois: The report of Mr. Wanenmacher and Mr. Gealy on the "Surface and Subsurface Structure of the Tri-County Oil Field of Southwestern Indiana" seems inconsistent with the facts presented.

The key horizon upon which their "surface" structure is mapped does not crop out at any place within the entire area covered. Throughout the producing area proper, Coal V, the horizon upon which their elevations are taken, is everywhere 70 feet or more deep, and all the data secured are from oil wells, coal tests, coal mines, et cetera. If this is to be interpreted as surface mapping, any horizon above the oil sand which might be used for determining structural conditions would serve to reveal surface structure. Of course, the interpretation hinges upon the definition of the word surface, but generally a stratum used to indicate surface structural conditions should crop out somewhere within the area mapped. If this is not the criterion, however, where is one to draw such a distinction? Perhaps at formation boundaries or at known unconformities, either of which is unsatisfactory.

However, be that as it may, there is no occasion for such a question to arise concerning the area under discussion. There is exposed throughout this entire region a limestone, called the Millersburg limestone, ranging from 3 to 14 feet in thickness, which can be used to show actual surface conditions. A local unconformity occurs at the base of this formation, one of several such features in the Pennsylvanian rocks of the state. This is the key horizon used in the original paper on this field submitted to the American Association of Petroleum Geologists in 1927, and the conclusions drawn at that time were based upon data from this horizon. Why, then, if Wanenmacher and Gealy wished to check the original maps and conclusions, did they not use the key horizon of the original paper? The new paper and maps neither disprove nor corroborate the original article; they merely represent additional data concerning the field.

As to the use of Coal V as a key horizon for depicting structural conditions, there are many limitations and qualifications to such work. The so-called "steel band" above this coal is not everywhere present; indeed, it is quite irregular in its occurrence. Hence a driller might not recognize the coal. Also, Coal V-A, which is a rider vein to V, locally becomes as thick and presents the same characteristics as V. This is, in many places, confusing to the driller and the geologist alike. The position of the "steel band" ranges from 2 to 35 feet above Coal V, or may be between Coal V and V-A or above both of them. These relations must be determined for any local area where the coal is used. The writer has long known that a "general positive" relation exists between the structure of Coal V and that of the oil sands or the Chester limestones above the oil sands. In fact, the first maps ever made of this region were upon Coal V, and they differ only in minor points from the map in the recent paper.

During the season of 1928-29, the writer had occasion to map (likewise with the plane table and alidade) much of the area immediately south of the Tri-County field, and later mapped the field itself. The Millersburg (surface)

limestone does not conform structurally with Coal V in much of this area, or in the Tri-County field. The writer can cite a well on a "dome or hill" in Coal V, where a decided syncline exists in the Millersburg limestone.

If Wanenmacher and Gealy had used the outcropping rocks of the area for determining surface structural conditions, their results and conclusions would most certainly have been different.

J. M. WANENMACHER and W. B. GEALY: Mr. Esarey's discussion seems to indicate that the surface structure, as shown on our map, does not represent the true structure of the surface rocks; therefore, that a comparison of this structure with the subsurface structure yields an erroneous impression. As his criticism is devoted chiefly to our choice of key bed, we think that it may be worth while to show cause for our selection.

In the first place, it must be stated that in determining the surface structure of rocks, the bed chosen for a key horizon should be the lowest bed that can be surveyed by surface methods, including core drill tests and coal tests as well as outcrop mapping. This bed may therefore be the lowest one that crops out on the surface of the region to be mapped, or it may be one which does not crop out in the area. Coal V, the key bed chosen by us, is the lowest horizon on which surface structure could be conveniently mapped. It does not crop out in the area shown on the map accompanying our paper, but it is within 30 feet of the surface in the eastern part of this area and it crops out about 1½ miles east of the eastern edge of the area shown on the map. Our investigation included the area of its outcrop, but we could see no particular value, as we did not know the subsurface structure there, in presenting the surface structure.

Secondly, we selected Coal V as our key bed in preference to the Millersburg limestone for the following reasons.

1. *It is lower stratigraphically.*—In this region, as in many others, irregularities in sedimentation and deformation may lower the value of surface structure for predicting subsurface conditions. The use of the lowest horizon as key bed is necessary if one wishes to eliminate errors produced by unconformities, thickening and thinning of beds, and other irregularities in the overlying formations. Therefore, if an unconformity occurs at the base of the Millersburg limestone (we found no evidence pointing to such a condition), our use of Coal V for key horizon has eliminated whatever error might have been produced. An illustration of the disastrous effect produced by choosing an upper horizon for key bed where the strata thicken and thin rapidly may be found in *U. S. Geol. Survey Bull. 691-C*, pp. 78 and 79.

2. *It is more persistent and more easily recognized.*—It was found, after a study of all available information, that Coal V is remarkably persistent throughout the area mapped. This bed has an economic value, and information concerning its occurrence is plentiful. Locally a rider vein overlies the main coal bed, but it is believed that this vein was detected where present and that proper corrections were made. In contrast to this, we found that good outcrops of the Millersburg limestone were scarce. This stratum tends to be lenticular and pinch out within short distances. Furthermore, as it occurs in places in two benches separated by shale, one must determine whether the outcrop is one of the two benches or whether it represents the total thickness of the bed.

Finally, it should be stated that our work was not undertaken for the purpose of checking that of Mr. Esarey, nor was our paper intended as a criticism of his original paper. However, we believe that the additional information secured by us demands attention and that our conclusions are justifiable.

GAIL F. MOULTON: The conclusions of Mr. Wanenmacher and Mr. Gealy in their paper on "Surface and Subsurface Structure of the Tri-County Oil Field of Southwestern Indiana" are consistent with the geologic history of the area as known at present. As stated in an earlier paper,[1]

> On the La Salle anticline near the Clark County (Illinois) oil fields, the pre-Pennsylvanian deformation seems to have been more pronounced than the post-Pennsylvanian deformation. Farther south, in southwestern Indiana and in Lawrence County, Illinois, the largest part of the deformation along the trend of the La Salle anticline occurred in post-Pennsylvanian time, as is shown by the essential parallelism of the Pennsylvanian and Chester beds.

The description of the Francisco field in a later part of the same paper gave general information regarding the geologic structure in that field and showed that the structure of the Chester formation is essentially similar.

Both the paper by Messrs. Wanenmacher and Gealy and the criticisms of their paper by Mr. Esarey overlook minor considerations which are of some importance. In regard to Mr. Esarey's objection to the use of coal V as a key bed for structural determination, it might be noted that many errors in correlation of that coal have been made by geologists who did not take the trouble to base their correlation on graphic records. The general sequence of the Pennsylvanian beds in southwestern Indiana is, as a rule, regular enough locally so that there should be little question of the correlation of the formation in one well with that in another near by. The fact that many coal tests have been drilled in the area of the Tri-County field makes a considerable quantity of data on the coal available for use. Because of the local unconformity at the base of the Millersburg limestone, mentioned in Mr. Esarey's discussion, it seems to me to be more desirable to use the coal bed for determining the structure of the shallow formations. In an investigation of the field made for the Gem Oil Corporation, one of the principal oil producers there, it was found that the structure of the coal seemed to be in closer accord with the structure of the Chester beds than that of any other shallow bed for which data were available.

The Chester sands in which production is obtained in the Tri-County field are very irregular. So marked is their lenticular character, in fact, that one is led to suspect that the accumulation of oil is as largely due to the presence of the high end of a local sand body in the producing areas as to the presence of any local dome or anticline. The only reason for the greater success of drilling in local structural "highs" in this field is that if sands are encountered in the general producing zone they are nearly certain to be the high parts of the local sand bodies and thus to be productive. Wells drilled on the slopes of the structure might find the high part of a lens; they also have a good prospect of reaching the sand lens low enough to find water.

[1] Gail F. Moulton and A. H. Bell, "Three Typical Oil Fields of the Illinois Region," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 119.

In an investigation of the Tri-County field in 1927, I concluded that irregularities of the surface of the Mooretown sand were so considerable that elevations on it were likely to be misleading. In order to avoid the probability that depositional irregularities would confuse the interpretation of the structures produced by folding, I used the base of the Beaver Bend limestone as a datum horizon. This contact is ordinarily readily recognized by the drillers, for the drilling action changes considerably on entering the Mooretown shale. Further, this contact generally is only 20 or 30 feet below a casing point, so that about the same degree of accuracy of depth measurements is obtained as for the top of the oil sand. If either Mr. Esarey or Messrs. Wanenmacher and Gealy had used this horizon for contouring the subsurface, the similarity of the structure of the shallow beds to that of the oil-producing formations would have been readily recognized. Accordingly, the degree of success resulting from drilling on well defined folds in the surface formations in this general area depends largely on the regularity of the producing sands.

GEOLOGY OF CATAHOULA PARISH, LOUISIANA[1]

H. K. SHEARER[2]
Shreveport, Louisiana

ABSTRACT

Catahoula Parish, Louisiana, is near the center of the Mississippi Valley syncline. Surface formations include beds of Recent, Pliocene, Miocene, Oligocene, and Eocene age. Wells drilled in this parish penetrate the Miocene Catahoula formation, the Oligocene Vicksburg formation, the Eocene Jackson formation, Claiborne group (subdivided into the Cockfield, Mount Lebanon, Sparta, and Cane River formations), and Wilcox formation. Good samples for paleontological study have been obtained from wells recently drilled, and will be of assistance in correlating the Louisiana formations with type localities in Mississippi and Alabama. No well in Catahoula Parish has been drilled into the Cretaceous, or even into the basal Eocene Midway formation. The structure is a southeast-dipping monocline with some terracing. There have been several gas blow-outs from different horizons, but no commercial gas production, and no definite showings of oil have been found.

GENERAL

Catahoula Parish is in east-central Louisiana, approximately 50 miles south-southeast of Monroe, Louisiana, 50 miles southwest of Vicksburg, Mississippi, and due west of Natchez, Mississippi. Tensas and Black rivers, forming the east boundary of the parish, flow south-southwest, in a general direction parallel with Mississippi River and 10-20 miles west of it. The parish is 50 miles long, from north to south, and has a maximum width of 27 miles in the northern part, tapering toward the south.

Until recently little was known regarding the subsurface structure and character of the Eocene formations underlying this area near the center of the Mississippi Valley. Several wells drilled during the past two years have given definite information regarding the thickness and variations of the formations, which will be of assistance in correlating the Eocene, Oligocene, and Miocene sections of Louisiana with the outcrops east of Mississippi River in Mississippi and Alabama.

The writer was present most of the time during the drilling of the Standard Oil Company of Louisiana's Tensas Delta No. 1 and Hunter *et al.* Tensas Delta No. 2 and No. 3. A complete report by J. C. Miller

[1]Read by title before the Association at the New Orleans meeting, March 20, 1930, Manuscript received by the editor, January 25, 1930. Published by permission of the Standard Oil Company of Louisiana, S. C. Stathers, chief geologist.

[2]Geologist, Standard Oil Company of Louisiana.

on samples from The Texas Company's Harris Hyman No. 1 was available by courtesy of The Texas Company. Samples from the Magnolia Petroleum Company's Montgomery No. 1 were examined and described by M. C. Israelsky while he was employed by the Standard Oil Company of Louisiana. Samples from The Texas Company's Tensas Delta No. B-1 were furnished by F. J. Miller, then chief geologist for The Texas Company in the Shreveport district, and examined by E. B. Hutson of the Standard Oil Company of Louisiana, who also made detailed paleontological reports on all the Hunter *et al.*, and all the Standard Oil Company's wells and examined samples received from the Leonard Petroleum Company's Knott No. 1 and the four wells drilled by the Lochnagar Oil and Gas Company.

In all, 19 wells have been drilled for oil and gas in Catahoula Parish, of which 12 are more than 3,000 feet deep, and 10 were drilled into the Wilcox formation.

This paper is intended as a summary of present knowledge regarding the geology and structure of Catahoula Parish. It is accompanied by an index map, two cross sections, a subsurface structure map, and a correlation table of the formations penetrated in the more important wells.

SURFACE GEOLOGY

Formations exposed in Catahoula Parish range from upper Eocene to Recent.

Jackson formation.—The outcrop of the Jackson formation, of Eocene age, is confined to the extreme northwestern part of the parish, in the vicinity of Rosefield. The outcrop area includes most of T. 11 N., R. 5 E., west of Ouachita River. The normal dip carries the beds below the surface, and they do not crop out at any place farther south in this parish.

The formation consists almost entirely of green or blue fossiliferous marine clay, weathering to plastic yellow clay.

Vicksburg formation.—The Vicksburg, the only formation of Oligocene age, is thin, not much more than 100 feet thick. In Catahoula Parish it crops out in a narrow belt south of the Jackson area, from Rosefield northeast to Ouachita River. The formation pinches out a few miles farther southwest, in La Salle Parish. On the northeast, there are no exposures of the Vicksburg in the bottom land between Ouachita and Mississippi rivers, but at the first exposures east of the Mississippi, in the vicinity of the type locality at Vicksburg, Mississippi, the formation is much thicker and is divisible into several members.

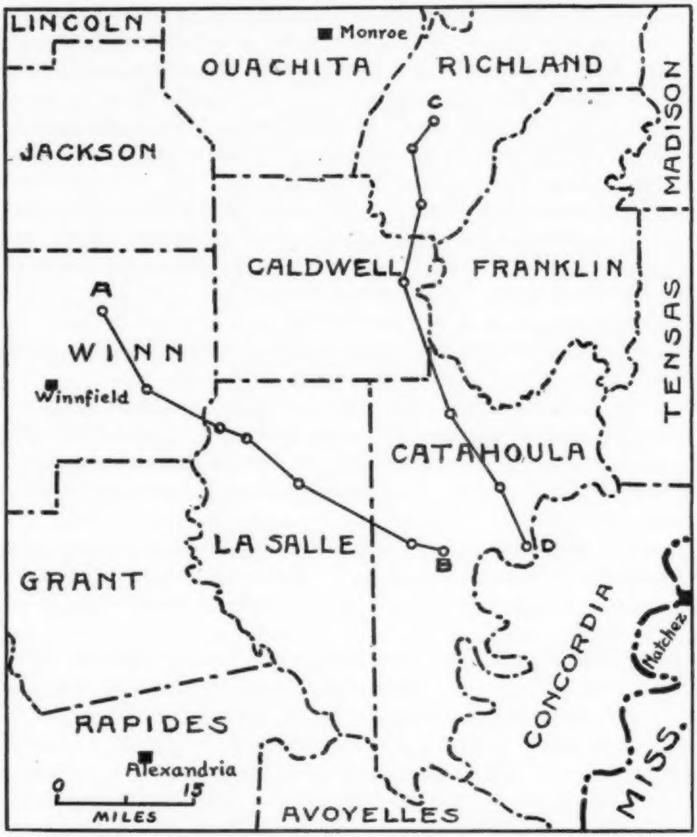


FIG. 1.—Index map showing location of Catahoula Parish, Louisiana, and structure sections (Figs. 3 and 4).

The Vicksburg formation in Catahoula Parish consists mostly of greenish, sandy clay. There is a thin bed of lignite at or near the base, and in the upper part is a bed of fossiliferous marl, not exceeding 5 feet in thickness, which weathers to form a line of conspicuous chert boulders on the outcrop.

Catahoula formation.—The Catahoula formation, of which Catahoula Parish is the type locality, is not fossiliferous, and was for a long time considered to be of Oligocene age, but is now correlated as lower

Miocene. It is the principal surface formation in the north half of the parish, the outcrop west of Ouachita River including everything north of the Rhinehart-Manifest-Harrisonburg road except the small area of Jackson and Vicksburg outcrop previously mentioned. There is also an isolated outlier of the Catahoula formation east of Ouachita River in the Sicily Island hills, including an area about 3 miles wide and 6 miles long across the central part of T. 10 N., R. 7 E.

The formation consists of white to light greenish clay, unconsolidated sand, cross-bedded sand and clay, and sandstone. All the materials indicate non-marine or shallow-water deposition, and fossils are lacking. Some of the sandstone beds are very hard and almost quartzitic. Although the hard sandstone makes up a relatively small part of the thickness of the formation, it is very conspicuous, because outcropping ledges form steep hills and bluffs.

As is typical throughout Mississippi, Louisiana, and East Texas, the Catahoula outcrop is an area of notably broken topography, with relief of 200 feet or more, because the beds of hard sandstone are more resistant to erosion than any of the Eocene or Oligocene formations exposed farther north.

Citronelle formation.—The Pliocene Citronelle formation caps most of the higher hills in the area of the Catahoula outcrop. This formation has its typical appearance, consisting principally of coarse red sand and gravel.

Port Hudson and Recent formations.—The part of Catahoula Parish west of Ouachita River and south of Rhinehart, Manifest, and Harrisonburg, and all east of the river except the Sicily Island hills, is bottom land. It is largely wooded and more or less swampy, but there are some low depositional ridges where the land is dry enough for cultivation. The surface formations are the Pleistocene Port Hudson sand and clay and more recent flood-plain deposits. All this part of the parish was covered by water ranging from 1 foot to 25 feet in depth during the Mississippi flood of 1927.

GEOLOGIC SECTION

The formations encountered in drilling in Catahoula Parish, commencing at the surface, are here described.

Recent and Port Hudson (Pleistocene).—The surface formation of clay and sand has an average thickness of about 50 feet in the bottom land west of Ouachita River. It is thicker east of that river, or closer to the Mississippi, reaching 140 feet in The Texas Company's Harris-

Hyman No. 1, which is the most southeasterly of the wells under consideration.

Citronelle formation (*Pliocene*).—A bed of coarse gravel 25 feet or more in thickness, and probably of Pliocene age, is found underlying the surface clay and sand, ordinarily between 50 and 100 feet in depth, in the wells located in the bottom land west of Ouachita River. East of the river the gravel is deeper and thicker, and is reported to range from a depth of 140 to 203 feet in The Texas Company's Harris-Hyman No. 1. In drilling, surface casing should be set below the base of this gravel, to prevent caving.

Catahoula formation (*Miocene*).—The Catahoula formation ranges in thickness from almost nothing at the edge of the outcrop in the northwestern part of the parish to possibly 1,000 feet in the extreme southern part. The thickness referable to this formation in The Texas Company's Harris-Hyman No. 1 is about 600 feet.

As the sands of the Catahoula formation produce strong artesian flows of sulphur water at locations in the bottom land, wells drilled through this formation must be supplied with plenty of mud and kept in operation continuously. The sandstone beds of the Catahoula, although very hard at the surface, do not cause any difficulty in drilling. Evidently these beds are only moderately indurated underground, and the extreme hardness of the outcrops is due to weathering and cementation by silica deposited from circulating water near the surface.

Vicksburg formation (*Oligocene*).—The thickness included as "Vicksburg and Jackson" in the accompanying correlations is measured from the top of the Vicksburg marl to the base of the Jackson formation. This does not include all of the Vicksburg, as there is a thin layer of that formation above the marl. In The Texas Company's Harris-Hyman No. 1, Vicksburg fossils were recognized 50 feet above the lime or marl; and in the Standard Oil Company's Tensas Delta No. 1, there is 40 feet of gumbo and gummy shale, probably belonging to the Vicksburg, above the marl. In this Standard well there is about 100 feet of sandy formation, which may be considered lower Vicksburg, below the marl, as the first Jackson fossils recognized were 108 feet below the top of the marl. In the Texas well the first definite Jackson was found 106 feet below the top of the marl. It is safe, therefore, to state that the total thickness of the Vicksburg is 150 feet in the Standard Oil Company's Tensas Delta No. 1, and increases only slightly toward the east.

The Vicksburg marl is the highly fossiliferous bed which forms typical chert boulders on the outcrop. It is a good horizon marker,

but is not ordinarily noticed in drilling unless watched for very carefully, because the thickness does not exceed 5 feet and the material is not much harder to drill than the adjacent shales. This bed was cored in both the Standard Oil Company's Tensas Delta No. 1, and Hunter *et al.* Tensas Delta No. 2 wells.

Jackson formation (*Eocene*).—The Jackson formation, after allowance is made for the probable thickness of similar Vicksburg beds at the top, ranges from 525 to 575 feet in thickness in all wells in Catahoula Parish. There is no great thickening in any direction within this area, but on the southwest, in Estabrook and Rogers' State No. 1, Sec. 33, T. 6 N., R. 3 E., Rapides Parish, where the Vicksburg is thin or absent, 688 feet of beds are referred to the Jackson formation.

The Jackson consists almost entirely of green clay-shale, more or less calcareous and fossiliferous. In the lower part there are some thin beds or lenses of sand, one of which, about 230 feet above the base of the formation, has produced a few barrels of oil at White Sulphur Springs, La Salle Parish. In the Standard Oil Company's Tensas Delta No. 1, cores were taken from two sandy beds in the Jackson.

Cockfield formation (*Eocene*).—The Cockfield beds in Catahoula Parish are similar to surface beds of that formation, consisting mostly of gray sand interbedded with gray or brown carbonaceous shale, and a few thin beds of lignite.

The top of the Cockfield, or contact with the Jackson, is generally well marked by a change from greenish shale to gray or lignitic sand and shale. A core from the Standard Oil Company's Tensas Delta No. 1 is believed to have cut the exact contact at a depth of 1,350 feet.

The lower contact of the Cockfield is obscure, because of a gradation downward into the Mount Lebanon formation. Cores from the lower Cockfield at 1,590, 1,625, 1,638, 1,685, and 1,712 feet in the Standard Oil Company's Tensas Delta No. 1 show alternating beds of non-marine gray and marine green sands, with a few *Foraminifera* in the marine beds, although the first fossils of definite Mount Lebanon types were not found above a depth of 1,796 feet. Some of these lower sandy marine beds are included in the stated thickness of the Cockfield in this and other wells some distance from the outcrop. It might be more consistent to limit the name Cockfield to non-marine beds and include all marine material in the underlying Mount Lebanon, but no distinct change is noted in well logs until the dominantly shaly beds of the latter formation are reached, and few cores have been taken in this part of the section.

The thickness referred to the Cockfield ranges from 436 feet in the Standard Oil Company's Tensas Delta No. 1, to 566 feet in the Magnolia Petroleum Company's Montgomery No. 1. The average is about 500 feet, and there is some thickening toward the east, but apparently not toward the south.

Mount Lebanon formation (*Eocene*).—The name "Mount Lebanon" has been used by Standard Oil Company geologists and a few others since 1924, in referring to the upper marine formation of the Claiborne. The beds of Claiborne age in Louisiana have been found to consist of four formations of practically equal importance, namely,

Claiborne group.....	Cockfield formation (non-marine)
	Mount Lebanon formation (marine)
	Sparta formation (non-marine)
	Cane River formation (marine)

The old St. Maurice formation included the lower three distinct formations, two marine and one non-marine. Spooner[1] used the name St. Maurice as restricted to the upper of the two marine formations, but this usage was not followed by a number of other geologists in the local area, who worked out the relations independently at about the same time, and considered it best to drop St. Maurice as a formation name to avoid confusion. Moreover, the exposure at St. Maurice is not very typical, as it represents only a small part of the upper Mount Lebanon beds, and is visible only at periods of low water.

The name Mount Lebanon is taken from the old town of Mount Lebanon in Bienville Parish, which is surrounded by good fossiliferous exposures. Harris and Veatch,[2] in 1899, mention the Hammett's branch exposure in Sec. 30, T. 18 N., R. 6 W., about 2 miles northeast of Mount Lebanon, as one of the classic "lower" Claiborne localities of the state, and refer to a previous description as early as 1888.[3]

The name "Minden formation" has also been proposed, but this is not considered as satisfactory as Mount Lebanon, because the typical exposures are several miles from Minden, and the formation there is not as characteristic as in Bienville Parish.

[1]W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), p. 235.

[2]G. D. Harris and A. C. Veatch, "Preliminary Report on the Geology of Louisiana," *Louisiana State Experiment Station Rept. on Geology and Agriculture*, Pt. 5 (1899), p. 85.

[3]L. C. Johnson, "The Iron Regions of Northern Louisiana and Eastern Texas," *50th Cong., 1st. Sess., House Ex. Doc.*, Vol. 26, No. 195 (1888), p. 20.

The Mount Lebanon, as here defined, is a marine formation, generally consisting of brown or green shale and glauconitic sand, and containing a characteristic fauna. Near the middle of the formation is a bed of hard, glauconitic, more or less sandy limestone, which forms characteristic boulder outcrops at or near Jonesboro, Milams, Calvin, Couley, Vowells Mill, Fisher, Columbus, and many other localities in Jackson, Winn, Natchitoches, and Sabine parishes. The limestone member becomes thinner northward, and grades into fossiliferous shale and sand in Bienville Parish.[1]

Since both the upper and lower contacts of the Mount Lebanon formation are gradational, its thickness in most of the wells around Harrisonburg, Catahoula Parish, is arbitrarily considered as 350 feet, 150 feet above and 200 feet below the top of the limestone member. This includes the maximum range of definite Mount Lebanon fossils, as determined in the different wells.

The total thickness of the shaly and sandy beds of the Mount Lebanon seems to increase very slightly toward the east, and the character of the beds indicates shallower-water depositional conditions. The limestone member in the Standard Oil Company's Tensas Delta No. 1 is 61 feet thick and consists of nearly pure, highly fossiliferous limestone. In Hunter *et al.* Tensas Delta No. 2, the thickness is only 26 feet. Farther east the limestone becomes very sandy, and is reported in some well logs as "hard sand" or "pack sand." Good cores from this horizon were secured in Hunter *et al.* Tensas Delta No. 1 and No. 3, where the limestone is sandy and less fossiliferous than the typical Mount Lebanon

[1]Since this paper was written two excellent correlation papers on the Claiborne of eastern Texas and northwestern Louisiana have been published, namely, "Lower Claiborne of East Texas, with Special Reference to Mount Sylvan Salt Dome and Salt Movements," by E. A. Wendlandt and G. M. Knebel, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1347-75, and "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," by A. C. Ellisor, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1335-46.

These authors divide the entire Claiborne group into several members, but do not make clear the definite four-fold division into formations in Louisiana; a division which evidently does not apply as distinctly in Texas or in the Alabama type section. The Mount Lebanon formation includes the Milams limestone and marl member in the middle, with the Crockett and Saline Bayou transitional members respectively below and above; and the Cane River formation evidently includes the combined Reklaw, Queen City, and Weches members, but is divisible into only two distinct members in Louisiana.

Either St. Maurice, Mount Lebanon, or Minden should be considered a Louisiana local name. According to C. L. Moody and others who have done detailed work in East Texas, the exposure at Cook Mountain, Houston County, Texas, is definitely on the same formation. If this is true, Cook Mountain should be used as the formation name, because it has priority over any of the other names which have been proposed for the formation as a whole or any of its members.

limestone farther west. The Texas Company's Tensas Delta No. B-1, and the Leonard Petroleum Company's Knott No. 1, which are the northernmost wells in Catahoula Parish, did not show any distinct bed of Mount Lebanon limestone.

Sparta formation (*Eocene*).—The Sparta formation, named for old Sparta, now almost deserted, but formerly the parish seat of Bienville Parish, in Sec. 15, T. 16 N., R. 7 W., like the Cockfield and Wilcox, is a non-marine formation consisting principally of light-colored sand, with some gray shale and lignite.

The thickness of about 600 feet is uniform throughout western Catahoula Parish and a large area on the north and west, being practically the same in the Standard Oil Company's Tremont No. 1, Sec. 1, T. 12 N., R. 2 W., Winn Parish, and in Estabrook and Rogers' State No. 1, Sec. 33, T. 6 N., R. 3 E., Rapides Parish. There is evidence of some thickening in eastern Catahoula Parish, and the sandy beds referred to this formation in the Magnolia Petroleum Company's Montgomery No. 1 are 692 feet thick.

Cane River formation (*Eocene*).—The name Cane River formation, derived from Cane River near the city of Natchitoches, is now in general use for the lower marine beds of the Claiborne group. The formation may be divided into two members, the Cane River clay above and the Cane River marl below.

The top of the upper member is sandy shale, which grades downward into smooth, plastic, slightly calcareous clay-shale. This material is characterized by its dark chocolate-brown color, generally specked and streaked with light green. It is all marine, and *Foraminifera* are plentiful.

The lower member consists of fossiliferous, sandy, highly glauconitic marl or soft limestone. It is commonly logged as "salt and pepper sand" because of the appearance of the white limestone with grains of dark glauconite.

The thickness of the Cane River ranges from about 333 feet in The Texas Company's Tensas Delta No. B-1, to more than 500 feet, becoming thicker toward the southeast. The Texas Company's Harris-Hyman No. 1 was drilled 537 feet into the Cane River without passing through it, but this well was evidently very near the base of the formation when abandoned.

The thickening is principally in the lower marl member. At the Standard Oil Company's Tensas Delta No. 1, where no marl was recognized in drilling and only a few fragments were found in the cuttings,

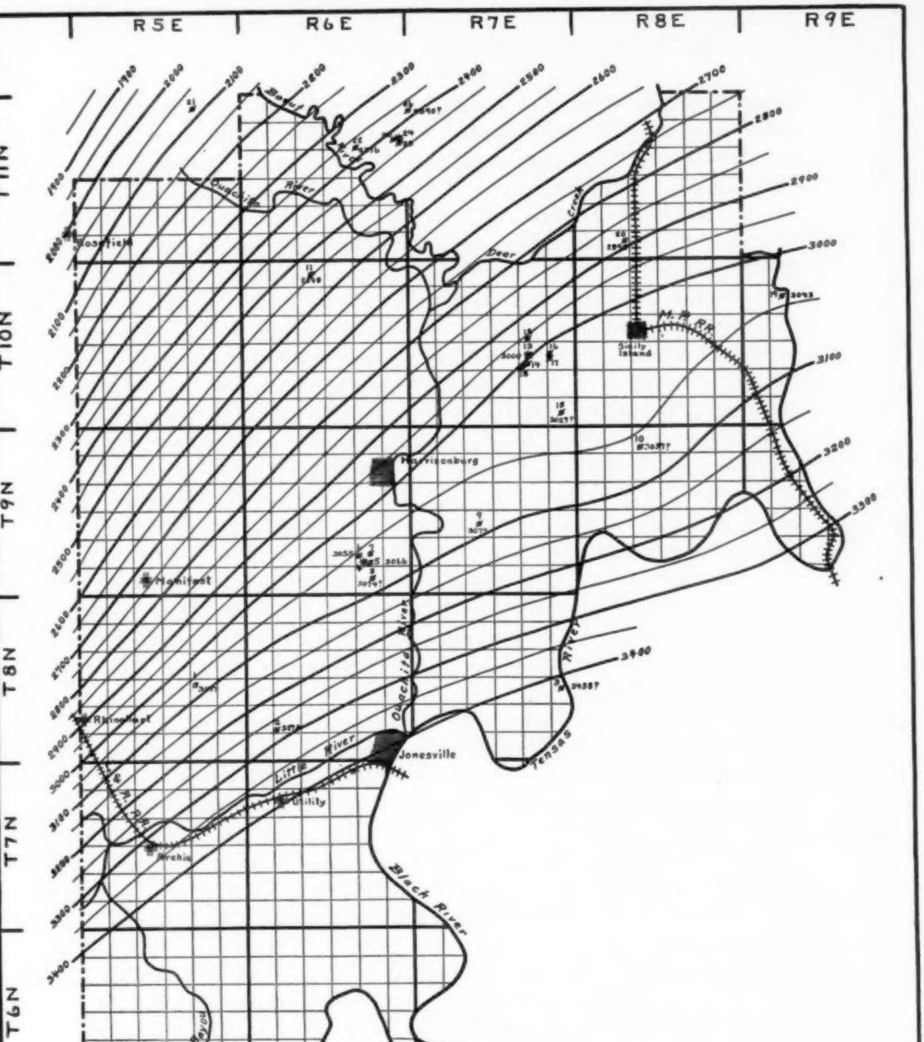

R5E
R6E
R7E
R8E
R9E
T11N
T10N
T9N
T8N
T7N
T6N
T5N
Rosefield
Harrisonburg
Manifest
Sicily Island
Jonesville
Utility
Archie
Rhinehart
Ouachita River
Little River
Black River
Tensas River
Deer Creek
Big Bayou
Lake Larto
M. P. RR.
STRUCTURE MAP OF
NORTHERN
CATAHOULA PARISH, LA.
Contours on the top of the Wilcox formation, depths below sea level.
H.K.Shearer.
Jan., 1929.

FIG. 2

TABLE I

LIST OF WELLS ON CATAHOULA PARISH MAP (FIG. 2).

Well	Location Section—Township, North—Range, East	Surface Elevation in Feet	Total Depth in Feet
1 Standard Oil Co. of La., Tensas Delta Lumber Co. No. 1	23-8-5	49	3,697
2 Lochnagar Oil & Gas Co., McMillan No. 1	29-8-6	58	3,506
3 The Texas Co., Harris-Hyman Lumber Co. No. 1	24-8-7	62	3,477
4 Lochnagar Oil & Gas Co., Beasley No. 1	26-9-6	55	3,098
5 Lochnagar Oil & Gas Co., Beasley No. 2	26-9-6	54	3,334
6 Lochnagar Oil & Gas Co., Beasley No. 3	26-9-6	61	3,120
7 Lochnagar Oil & Gas Co., Taliaferro No. 1	26-9-6	..	900
8 Ferguson & Kimbrough, Nichols No. 1	35-9-6	66	2,219
9 S. D. Hunter *et al.*, Tensas Delta Lumber Co. No. 2	21-9-7	50	3,190
10 S. D. Hunter *et al.*, Tensas Delta Lumber Co. No. 3	4-9-8	56	2,109
11 The Texas Co., Tensas Delta Lumber Co. No. B-1	4-10-6	58	3,500
12 Sicily Island Oil & Gas Co., Hardin No. 2	14-10-7	..	1,630
13 Dittenhaver & Ayers, Hardin No. 1	23-10-7	75?	3,212
14 Catahoula Oil & Development Co., Hardin No. 1	23-10-7	..	1,864
15	23-10-7	..	1,100
16 Rowe & O'Donnell, Causey No. 1	24-10-7	..	2,735
17 Rowe & O'Donnell, Causey No. 2	24-10-7	..	3,004
18 S. D. Hunter *et al.*, Tensas Delta Lumber Co. No. 1	36-10-7	60?	2,012
19 Magnolia Petroleum Corp., Montgomery No. 1	8-10-9	60?	3,366
20 Leonard Petroleum Co., Knott No. 1	32-11-8	72	4,765
21 Southern Crude Oil Purchasing Co., Caldwell Land & Timber Co. No. 7	2-11-5	62	1,000
22 Louisiana Petroleum Co., Tensas Delta Lumber Co. No. 1	11-11-6	70?	2,503
23 The Exploration Co., Moore No. 1	12-11-6	70?	2,120
24 Cowell *et al.*, Moore No. 2	12-11-6	70?	1,385
25 Pittsburg Exploration Co., Moore No. 3	12-11-6	70?	2,501
26 Louisiana Petroleum Co., Daily No. 1	6-11-7	70?	2,214

the thickness correlated as Cane River is only 401 feet, increasing about 80 feet in 3 miles southeast to the Lochnagar Oil and Gas Company's McMillan No. 1, where the lower marl is approximately 30 feet thick. Such local variations are evidently due to an erosional unconformity, which left small hills in the Wilcox surface on which the Cane River formation was laid down.

Wilcox formation (*Eocene*).—The Wilcox is dominantly a sandy and lignitic, non-marine formation. The upper beds in the Catahoula Parish wells consist of highly micaceous sand or sandy shale. This micaceous character persists throughout a large area, and is also observed in the top of the Hatchetigbee (upper Wilcox) formation in Mississippi and Alabama. The upper sand bed of the Wilcox, just below the Cane River marl, is the oil-producing formation in the Urania field in La Salle Parish, and most of the wells in Catahoula Parish were drilled primarily for the purpose of testing this horizon.

The Wilcox in Catahoula Parish contains some distinct marine beds, similar to those seen in the southern part of the Louisiana Wilcox outcrop, especially in Sabine Parish. One of these beds was cored at 3,258 feet, or 132 feet below the top of the formation, in the Standard Oil Company's Tensas Delta No. 1. This is a dark green, glauconitic sandy shale with *Foraminifera* and fragments of larger marine fossils. There is also some calcareous material, possibly marine, in the last core from 3,687 to 3,697 feet in the same hole.

The Leonard Petroleum Company's Knott No. 1 was drilled 1,798 feet below the top of the Wilcox, which is much deeper stratigraphically than any other well in the parish. No samples are available from the lower part of this well, but the log suggests that at the total depth of 4,765 feet, drilling was still in the Wilcox formation, and had not even reached the top of the Midway. The Texas Company's Tensas Delta No. B-1 and the Standard Oil Company's Tensas Delta No. 1 were drilled 896 and 571 feet, respectively, into the Wilcox formation.

The Standard Oil Company's Tremont Lumber Company No. 1, in Sec. 1, T. 12 N., R. 2 W., Winn Parish, 40-50 miles northwest of the wells mentioned, had a thickness of 2,363 feet of Wilcox and Midway, of which at least 1,385 (possibly 1,564) feet was Wilcox. These formations are evidently hundreds of feet thicker in Catahoula Parish. Therefore, the top of the Cretaceous should be found at a depth of more than 5,000 feet in the northwestern part of the parish, and would be below any practicable drilling depth at present in the southern part.

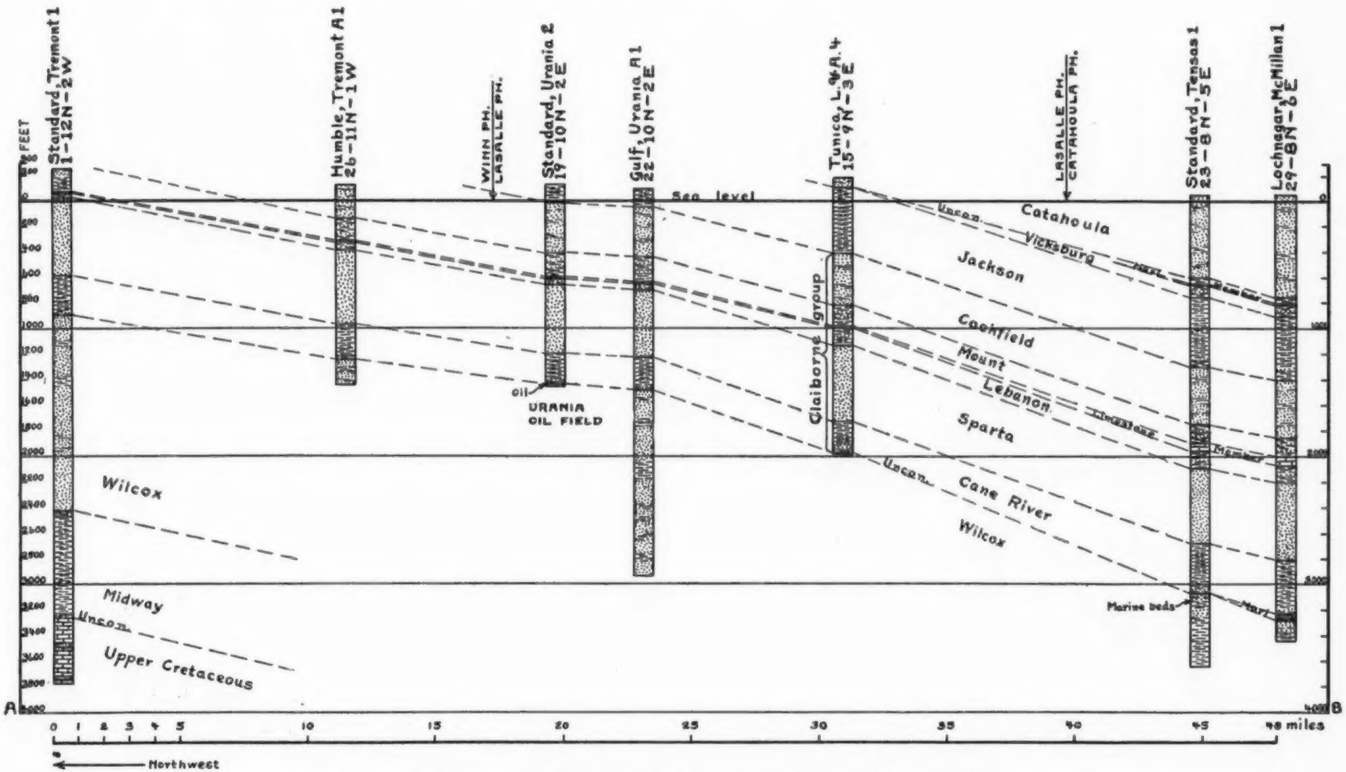


FIG. 3.—Structure section in Winn, La Salle, and Catahoula parishes, Louisiana.

STRUCTURE

The structure in the northern part of Catahoula Parish, as contoured on the top of the Wilcox formation, is shown in Figure 2. This shows a general monoclinal southeast dip, with a terrace between, and south of, Harrisonburg and Sicily Island.

This terrace is determined principally by Hunter *et al.* Tensas Delta No. 1 and No. 3, neither of which was drilled deep enough to reach the Wilcox. If the top of the Mount Lebanon limestone is used as a key horizon, there may be either a northwest (reverse) dip of 22 feet or a southeast (normal) dip of 20 feet, which is, however, much less than the normal rate of dip. Because of the southeastward thickening of the formations, a very slight reversal in the upper formations does not necessarily indicate a reversal on the top of the Wilcox.

No salt domes are known in Catahoula Parish. There is no surface evidence of doming in the outcrop area of the Catahoula and older formations in the northern part of the parish. In the bottom land of the southern and eastern parts salt domes, if present, could be located only by geophysical methods. This is not, however, in a recognized salt-dome area, and it is very improbable that domes will be found.

Gas blow-outs.—The Lochnagar Oil and Gas Company's Beasley No. 1, Sec. 26, T. 9 N., R. 6 E., made a blow-out, estimated at 500,000 cubic feet of gas with salt water at a depth of 2,200 feet, with casing set at 2,185 feet. The blow-out lasted only a short time. After being drilled to 3,093 feet, with casing set at 2,686 feet, the well made another blow-out, lasting about 30 minutes, at an estimated rate of 30,000,000 cubic feet per day. The well then bridged over or sanded up, and after being cleaned out it made nothing but salt water. The first blow-out came from the Sparta sand and the second from near the base of the Cane River. Two deeper wells drilled later in the same section made no showings of gas at these horizons.

Six wells were drilled at different times between the years 1914 and 1923 within a small area in the eastern part of T. 10 N., R. 7 E., about 3 miles west of Sicily Island. In all of them gas showings were reported between depths of 1,100 and 1,600 feet, and one well, Dittenhaven and Ayers' Hardin No. 1, Sec. 23, T. 10 N., R. 7 E., had a gas blow-out at a depth of 1,569 feet. The gas in these wells came from the Cockfield formation.

About a mile from the northern boundary of Catahoula Parish, Cowell *et al.* Moore No. 2 in Sec. 12, T. 11 N., R. 6 E., made a strong blow-out of gas and salt water while drilling in gumbo at 1,385 feet.

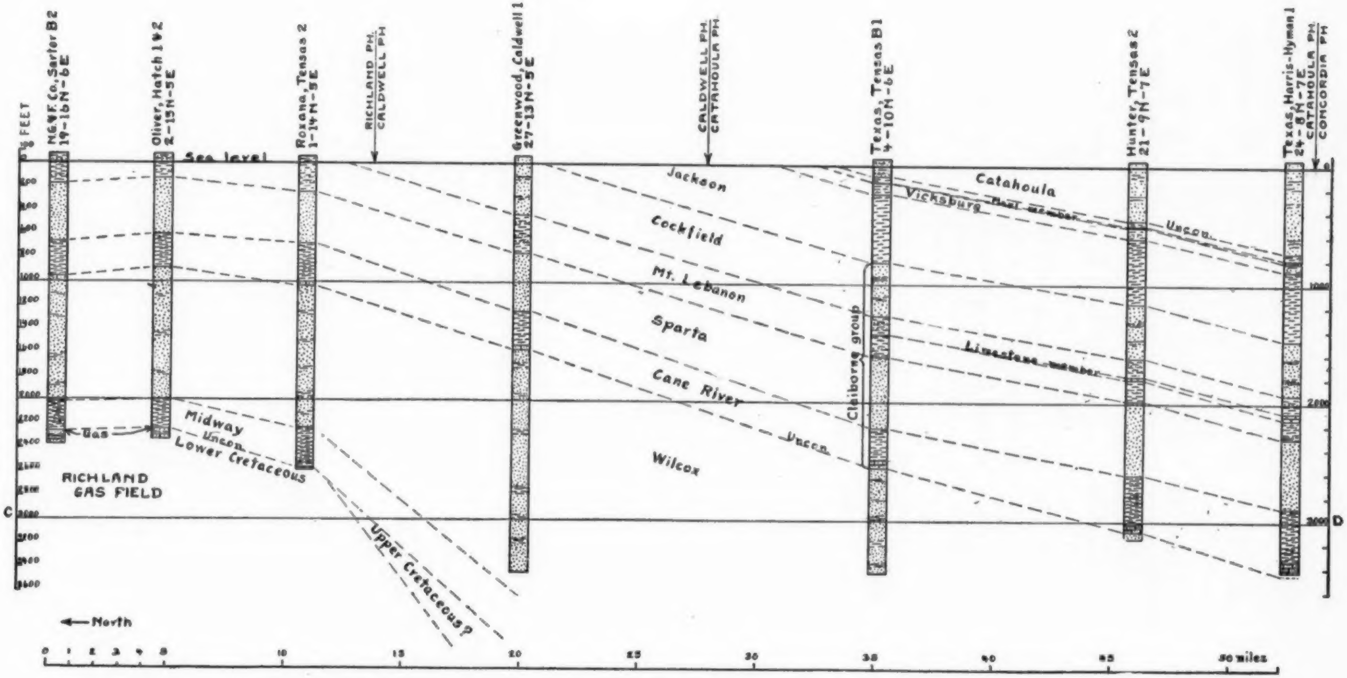


FIG. 4.—Structure section in Richland, Caldwell, and Catahoula parishes, Louisiana.

As only surface casing was set, the gas is believed to have come from the top of the Cockfield formation, at a little below 700 feet. Like other blow-outs in Catahoula Parish, this lasted only an hour or two. Two other wells were drilled in the same section; gas showings were reported in one at 774 and 1,900 feet.

These blow-outs indicate that limited quantities of gas have accumulated in several sandy formations at certain localities in and near Catahoula Parish. The cause of such accumulations may be very small anticlinal structures, small faults, or the pinching-out of sand beds. Up to the present none of them has shown any commercial quantity of gas, and there has been no authenticated showing of oil in any well in the parish.

TABLE II

STRATIGRAPHIC CORRELATION OF WELLS IN OR NEAR CATAHOULA PARISH, LOUISIANA

STANDARD OIL COMPANY OF LOUSIANA'S TENSAS DELTA NO. 1
Sec. 23, T. 8 N., R. 5 E. Elevation, 49.0 feet

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 695	695
Vicksburg and Jackson	695-1,350	655
Cockfield	1,350-1,786	436
Mount Lebanon	1,786-2,136	350
Sparta	2,136-2,725	589
Cane River	2,725-3,126	401
Wilcox	3,126-3,697	571 +

LOCHNAGAR OIL AND GAS COMPANY'S McMILLAN NO. 1
Sec. 29, T. 8 N., R. 6 E. Elevation, 58.0 feet

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 806	806
Vicksburg and Jackson	806-1,461	655
Cockfield	1,461-1,905	444
Mount Lebanon	1,905-2,255	350
Sparta	2,255-2,855	600
Cane River	2,855-3,334	479
Wilcox	3,334-3,506	172 +

TABLE II—*Continued*

TEXAS COMPANY'S HARRIS-HYMAN NO. 1
Sec. 24, T. 8 N., R. 7 E. Elevation, 62.0 feet (estimated)

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 844	844
Vicksburg and Jackson	844-1,520	676
Cockfield	1,520-1,980	460
Mount Lebanon	1,980-2,353	373
Sparta	2,353-2,940	587
Cane River	2,940-3,477	537 +

LOCHNAGAR OIL AND GAS COMPANY'S BEASLEY NO. 2
Sec. 26, T. 9 N., R. 6 E. Elevation, 54.0 feet

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 565	565
Vicksburg and Jackson	565-1,220	655
Cockfield	1,220-1,680	460
Mount Lebanon	1,680-2,030	350
Sparta	2,030-2,640	610
Cane River	2,640-3,118	478
Wilcox	3,118-3,334	216 +

HUNTER *et al.* TENSAS DELTA NO. 2
Sec. 21, T. 9 N., R. 7 E. Elevation, 50.0 feet

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 548	548
Vicksburg and Jackson	548-1,203	655
Cockfield	1,203-1,668	465
Mount Lebanon	1,668-2,018	350
Sparta	2,018-2,646	628
Cane River	2,646-3,127	481
Wilcox	3,127-3,190	63 +

TEXAS COMPANY'S TENSAS DELTA NO. B-1
Sec. 4, T. 10 N., R. 6 E. Elevation, 58.0 feet

Formation	*Depth in Feet*	*Thickness in Feet*
Recent and Catahoula	0- 195	195
Vicksburg and Jackson	195- 875	680
Cockfield	875-1,327	452
Mount Lebanon	1,327-1,677	350
Sparta	1,677-2,271	594
Cane River	2,271-2,604	333
Wilcox	2,604-3,500	896 +

TABLE II—*Continued*

MAGNOLIA PETROLEUM CORPORATION'S MONTGOMERY NO. 1
Sec. 8, T. 10 N., R. 9 E. Elevation, 60.0 feet (estimated)

Formation	Depth in Feet	Thickness in Feet
Recent and Catahoula	0- 308	308
Vicksburg and Jackson	308- 994	686
Cockfield	994-1,560	566
Mount Lebanon	1,560-1,938	378
Sparta	1,938-2,630	692
Cane River	2,630-3,110	480
Wilcox	3,110-3,366	256 +

LEONARD PETROLEUM COMPANY'S KNOTT NO. 1
Sec. 32, T. 11 N., R. 8 E. Elevation, 72.0 feet

Formation	Depth in Feet	Thickness in Feet
Recent and Catahoula	0- 252	252
Vicksburg and Jackson	252- 899	647
Cockfield	899-1,449	550
Mount Lebanon	1,449-1,818	369
Sparta	1,818-2,493	675
Cane River	2,493-2,967	474
Wilcox	2,967-4,765	1,798 +

STANDARD OIL COMPANY OF LOUISIANA'S TREMONT NO. 1
Sec. 1, T. 12 N., R. 2 W. Elevation, 255.0 feet
Winn Parish

Formation	Depth in Feet	Thickness in Feet
Mount Lebanon	0- 224	224
Sparta	224- 830	606
Cane River	830-1,146	316
Wilcox and Midway	1,146-3,509	2,363
Upper Cretaceous	3,509-4,024	515 +

ESTABROOK AND ROGERS' STATE NO. 1
Sec. 33, T. 6 N., R. 3 E. Elevation, 50.0 feet (estimated)
Rapides Parish (Catahoula Lake)

Formation	Depth in Feet	Thickness in Feet
Recent and Catahoula	0- 717	717
Jackson	717-1,405	688
Cockfield	1,405-1,825	420
Mount Lebanon	1,825-2,235	410
Sparta	2,235-2,861	626
Cane River	2,861-3,337	476
Wilcox	3,337-3,540	203 +

GENERATION OF OIL IN ROCKS BY SHEARING PRESSURES[1]

III. FURTHER EFFECTS OF HIGH SHEARING PRESSURES ON OIL SHALES

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ABSTRACT

This paper contains results of research performed in the year 1928-29 on the generation of oil from possible source rocks of petroleum by high shearing pressures. An account of the earlier work has appeared in this *Bulletin*. High shearing pressures applied on oil shales from many localities, and on cannel coal, at room temperatures, failed to generate oil. Nearly all the specimens treated yield more soluble organic matter on extraction with chloroform than do rocks not sheared. Except in oil shale from Indiana, this increase in soluble matter is due largely to the physical effects of pressure in comminuting the rock, rather than to chemical changes produced in the organic compounds. The Indiana shale after pressure shows a large increase in soluble organic matter which is not wholly accounted for by physical changes. Most of the sands encased with the shales during shearing were found afterward to contain slight amounts of soluble organic matter which must have migrated from the shale. This, though explained also by purely physical changes in state of some of the organic matter, supports the theory of devolatilization of organic rocks by shearing pressures. Quantitatively, however, except in the oil shale from Indiana, it has still to be shown that shearing pressures exerted at room temperatures are important in converting the organic matter of such possible source rocks of petroleum into oil.

INTRODUCTION

During 1928 and 1929 experiments have been made to determine the effect of high shearing pressures on oil shales previously tested and on additional samples recently obtained. The work is a continuation of that already described in this *Bulletin*.[3] The purpose of the investigation is to determine whether or not high shearing pressures may be

[1]Manuscript received by the editor, February 1, 1930. This paper contains results obtained in an investigation on "The Generation of Oil in Rocks by Shearing Pressures," listed as Project No. 1 of the American Petroleum Institute Research. Financial assistance in the work has been received from a research fund of the American Petroleum Institute donated by the Universal Oil Products Company. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. W. J. Mead is director of the project. W. P. Rand, junior research fellow, University of Wisconsin, has assisted in the experimental work described herein.

[2]Former American Petroleum Institute research fellow, Department of Mineralogy, Queen's University. Introduced by W. H. Twenhofel.

[3]*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 303-65.

important in converting complex organic matter, such as occurs in typical oil shales or cannel coal, to simpler hydrocarbons or to oil. There are many factors, such as heat and catalytic agents, which may be combined with pressure to produce such an effect, but here only the effects of shearing pressures at room temperatures are considered.

Recent experiments differ from those already described in that much higher pressures have been applied to such rocks, and their deformation has been effected under greater containing pressures. Ordinarily, a seeming effect of higher pressures is to increase the soluble organic content of the sheared rocks by amounts which may be as much as 40 per cent of the total soluble matter of the unsheared specimens. The increase in extractable matter, however, does not vary directly or proportionally with the pressures applied, and is more seeming than real, as it is generally related to the comminution of shale particles and an increase in surface which permits more rapid solution by organic solvents. Shale from Indiana seems to be an exception. This shale, after shearing, shows a much greater increase in soluble organic matter than do all other samples. The increase is only partly related to comminution of shale particles, and in part may be due to some other effect, such as a chemical reaction, caused by the shearing pressures.

As in the early phase of the investigation, various problems have arisen in the course of the work. These relate to the effect of size of particles of shale on extraction with chloroform, the relation of high shearing pressures to size of particles produced, the relative rates of oxidation of the organic material in different rocks, and the influence of oxidation on the amount of extractable matter. These will be considered before the results of the shearing-pressure tests.

Acknowledgments

The experimental work herein described has been carried out by Wendell P. Rand and the writer in the geological laboratories of the University of Wisconsin. W. J. Mead, the director of the project, has given helpful suggestions and criticisms, as has David White, the sponsor of the research.

Experiments Incidental to Shearing-Pressure Tests

SHEARING AND SIZE OF SHALE PARTICLES DEVELOPED BY SUBSEQUENT GRINDING

It has been pointed out[1] that high shearing pressures on oil shale necessarily form much finer particles than result from simple hand

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 345.

grinding. To substantiate this and to secure accurate data, further experiments were made.

A large sample of coarsely ground Colorado shale was divided into four samples, three of which were sheared in short steel cylinders with a ⅛-inch wall. The cylinders were compressed by loads of differing weights applied parallel with their long dimension. All samples of shale were ground later in a mechanically stirred mortar to pass an 80-mesh screen. A shorter period of later grinding was needed to bring the sheared samples to the required size. One-half of each of the sheared samples was then ground for the same length of time as the unsheared shale, giving finer and finer material.

The results are shown in Table I.

TABLE I

Sample	*Pressure in Pounds*	*Minutes Ground to Pass 80-Mesh*	*Screen Analysis* 80–200 Mesh Per Cent	200–300 Mesh Per Cent	−300 Mesh Per Cent
1	Nil	100	80.21	10.44	9.34
2	100,000	85	81.72	10.14	8.13
3	150,000	45	82.51	9.35	8.14
4	200,000	20	75.92	12.57	11.49
2*a*	100,000	100	66.41	13.64	19.93
3*a*	150,000	100	17.84	33.52	48.63
4*a*	200,000	100	2.68	9.91	87.40

The results indicate that shearing shale in steel tubes so shatters the shale that it may be reduced to less than 80-mesh in time intervals which vary inversely as the pressure. Although the screen analyses of samples 1-4 do not indicate that shale particles of much finer size are produced by shearing than by ordinary grinding alone, the analyses of samples 2*a*-4*a* show that the more highly sheared shale breaks down to much finer particles in a specified time interval of grinding and that the shale particles are more strained and probably more fractured as the shearing pressures are increased.

EFFECT OF SIZE OF PARTICLES ON RECOVERY OF EXTRACT

Australian shale.—Previous experiments on Colorado shale indicated that for a 24-hour period of extraction with chloroform, grinding the shale to much less than 80-mesh—to as fine as 200-mesh—did not appre-

ciably affect the recovery or rate of extraction of soluble organic matter for that shale. As shown later, this conclusion is modified. Similar tests on a sample of Australian shale have been made. The sample was divided in two, one-half being ground to just pass an 80-mesh screen, the other to pass a 300-mesh screen. The extracts were removed and weighed at specified intervals, but the total extraction period was 24 hours. The results are given in Table II, which also shows similar runs on two samples of unsheared and sheared Australian shale, both of which were ground to pass an 80-mesh screen.

TABLE II

TESTS SHOWING EFFECT OF SIZE OF PARTICLES ON RECOVERY

	Test A (-80-Mesh)	*Test B* (-300-Mesh)	*6 T U* *Unsheared* (-80-Mesh)	*6 T X* *Sheared* (-80-Mesh)
Dry weight shale	9.9935	9.9855	9.9899	9.9923
Per cent H_2O + volatiles	.065	.145	.105	.075
Net Weight Extract				
Repeated extraction	.0612	.0829	.0624	.0919
	.0076	.0115	.0116	.0095
	.0033	.0051	.0046	.0045
	.0084	.0026	.0052	.0036
	.0021	.0023		
24 hours	.0224	.0251	.0261	.0298
Total	.1050 grams	.1295 grams	.1099 grams	.1393 grams
Extract per cent of dry shale	1.03	1.298	1.10	1.394

The results indicate that for Australian shale finer grinding of the shale particles causes an increase in yield of extract. The increase is manifested in the first siphon of solvent and extract and is maintained through the 24-hour period of extraction. Somewhat similar results were obtained in extracting shale from pressure test 6 *T*, which was sheared in a steel tube with a load of 300,000 pounds. In this test the first and last extracts obtained from the sheared shale are greater than from the unsheared sample. The experiment suggests that the soluble matter has been made more soluble or more available by the shearing. As noted previously, the sheared shales are clearly more strained and fractured than shales not highly sheared, as they break down more rapidly

on continued grinding. Hence, the increase in yield may be due simply to the physical nature and size of the shale particles.

Other oil shales.—Experiments on other oil shales were made to determine the effect of fine grinding on the recovery of extract. Lots of the same shale were extracted with chloroform for 24 hours after being ground to -80- and -300-mesh. The results are shown in Table III.

TABLE III

Shale	*Per Cent Extract*			*Difference*	*Per Cent Difference*
	-80-Mesh	*-200-Mesh*	*-300-Mesh*		
Colorado	1.952* 1.93	2.12 2.12		+.162 +.19	+8.3 +9.8
Indiana	2.158		2.21 2.176	+.052 +.018	
				Av.+.035	+1.62
Kentucky	.799		.918	+.119	+14.9
Manchurian	.713		.720	+.007	+ .98

*See Tests, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 311.

The results are significant. In all these experiments, a finer grinding of the shale to -300-mesh gave an increase in extract. The percentage differences shown in the last column are based on the amount of extract recovered from the 80-mesh shale. The figures are not strictly comparable without complete screen analyses of all samples, as it is not possible to grind all to exactly the same size, and the percentages of shale passing different mesh sieves will differ. The results for the Colorado shale are not at variance with previous tests[1] in which the shale was reduced only to -200-mesh size, though in those it was concluded that this amount of fine grinding did not appreciably affect the solubility of the organic matter. The Indiana shale, though relatively rich in soluble organic matter, shows little effect of the grinding, as does the leaner shale from Manchuria. The increase in extract from the Kentucky shale is appreciable and well above the limits of experimental error.

The importance of these results will be seen later in connection with the extraction data of shales when sheared. The fine grinding of these shales and comparable unsheared samples eliminates, in many of them,

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 311.

marked differences in extract, though the equalization of the amounts of extract from sheared and unsheared samples is brought about partly by an increase in extract from the unsheared samples and also by a decrease in that from the sheared shales. Possible reasons for this decrease will be dealt with later.

The increase in extract from shales ground to -300-mesh may be attributed most naturally to the greater amount of surface available for attack by the solvent. As it is impossible to grind the shale without the exertion of considerable shearing pressures, it can not be said that the actual pressure did not cause some change in the solubility of the compounds present. The burden of proof, however, is on supporters of the latter hypothesis.

RATE OF OXIDATION OF OIL SHALES AND CANNEL COAL

It has been found that oxidation of extracted Colorado oil shale causes an increase in soluble organic matter; hence, that oxidation is a factor in converting complex organic substances in such rocks to lighter, soluble hydrocarbons.[1] Accordingly, tests have been made on similar rocks to determine their relative rates of oxidation.

Samples of oil shale from Colorado, Australia, Indiana, Kentucky, Manchuria, and of cannel coal from Kentucky, were ground to -300-mesh and heated in air in an electrically regulated oven at 105°C. for periods of time totalling 320 hours. All samples lost moisture and volatiles, and then gained in weight as a result of oxidation. Total gains in oxygen were calculated on the lowest dry weight obtained. Actually, the figures obtained represent the net gain in weight over and above losses of moisture and volatile organic matter. The results are summarized in Table IV.

TABLE IV

Sample	*Per Cent Gain of Oxygen*
Cannel coal	2.115
Colorado shale	2.06
Australian shale	1.935
Indiana shale	1.814
Manchurian shale	0.523
Kentucky shale	0.448

The gains in oxygen seem to be controlled by the nature of the organic matter in the different samples, as they are not proportional to

[1] *Op. cit.*, pp. 313-17.

the total organic content. Previous work[1] suggests that the amount of oxidation is related to the content of unsaturated hydrocarbons present. It may be observed that the Indiana shale, which seems more affected by shearing pressures than any of the others, is not peculiar in its rate of oxidation.

RATE OF OXIDATION OF SHEARED AND UNSHEARED SHALE

Colorado shale.—To test further the idea that shales sheared should oxidize more rapidly than those not sheared, as the pressures produce greater surface or potentially finer particles than a moderate amount of hand grinding, samples of Colorado shale listed in Table I were oxidized at 105°C. for 264 hours. The more significant results are given in Table V; No. 1 is the coarser grained, and No. 4*a*, the finer.

TABLE V

Sample Number	*1*	*2a*	*3a*	*4a*
Shearing Pressure in Pounds	Nil	100,000	150,000	200,000
Hours Heated	*Total Gain Per Cent by Oxidation*			
12	.005	.015	.010	.020
24	.071	.095	.125	.130
120	.408	.408	.416	.431
144	.504	.509	.494	.502
264	.747	.789	.749	.765

Table V shows that in the earlier stages of oxidation the more highly sheared shale (No. 4*a*) gains weight more rapidly than the unsheared or less sheared shales. After 144 hours of heating all samples gain in weight by nearly equal amounts. It is noteworthy that the sheared shales gained oxygen more rapidly in spite of the fact that they may have been partly oxidized during the shearing.

Indiana shale.—Other oxidation tests were made on unsheared and sheared Indiana shale. Both samples were ground to pass a 300-mesh screen and oxidized for 320 hours. The unsheared Indiana shale gained more oxygen throughout than the sheared sample.

	Per Cent Gain in Oxygen
Unsheared shale	1.814
Sheared shale, 500,000-pound load	1.688

Though the results are opposite to those for Colorado shale, a possible explanation is offered. Oxidation of the sheared sample may have

[1] *Op. cit.*, p. 315.

occurred during shearing. As the amount of oxidation for any one sample is limited, later oxidation at 105°C. would not show as great gains as are found for the unsheared shale.

EFFECT OF OXIDATION OF INDIANA SHALE ON EXTRACTABLE MATTER

It has been shown that when Colorado shale is oxidized after first being extracted with an organic solvent, some of the insoluble organic matter is rendered soluble.[1] Similar tests were made on -80-mesh Indiana oil shale. A sample was divided into three parts. One part was extracted for three periods of 24 hours each with chloroform; a second was first extracted and then oxidized between subsequent periods of extraction; a third part was oxidized before any extraction. The results are shown in Table VI.

TABLE VI

OXIDATION-EXTRACTION TESTS ON INDIANA OIL SHALE

Test Numbers		*1-10*		*1-11*		*1-12*	
Extraction Hours		*Hours Oxidized*	*Per Cent Extract*	*Hours Oxidized*	*Per Cent Extract*	*Hours Oxidized*	*Per Cent Extract*
1st	24	Nil	2.225	Nil	2.215	48	2.05
2nd	24	Nil	.312	66	.547		
3rd	24	Nil	.173	24	.227		
Total			2.710		2.989		

Percentage increase in extract in 1-11 = .279
Percentage change = +10.3

As with the Colorado shale, oxidation of unextracted Indiana shale at 105°C. causes a loss of soluble organic matter. The loss may be attributed largely to loss of volatiles during the heating and oxidation.[2] Oxidation of previously extracted Indiana shale causes an increase of 10 per cent of the originally soluble material for a total period of 90 hours' oxidation at 105°C. Comparable figures for Colorado shale are not available, though similar results were obtained with this shale. Though oxidation of Indiana shale may occur at room temperatures, as the shale is being sheared, it is clear that any marked increase in soluble matter (increases as large as 38 per cent have been obtained)

[1] *Op. cit.*, pp. 313-17.

[2] *Ibid.*, p. 313.

can not be attributed solely to the effects of oxidation, especially in view of the marked differences in temperature of the shale while being sheared and while being oxidized at 105°C. as in the foregoing experiments.

Shearing-Pressure Experiments

TYPES OF EXPERIMENTS

Tests on different oil shales have been made in which the shales yield to pressure either largely by fracture or by flowage. In the former type, 7-inch lengths of semi-annealed Shelby steel tubing with ¼-inch wall were used. The tubes have a 1-inch diameter inside, and are closed at each end by solid brass nuts and lead washers. Where possible, solid diamond-drill cores of shale, 1 inch in diameter and 3.5 inches long, were inserted in the center of the tubes and the ends packed with 20-28-mesh Ottawa sand. Powdered oil shale of -35-mesh was used where solid cores could not be obtained. To prevent the mixing of shale and sand in the tubes, a single thickness of fat-free paper was placed between them in the tubes. Though the paper was largely destroyed by the pressure, the contamination of sand by shale was generally prevented.

Difficulty was experienced with the heavy tubing used, as it would fail by cracking before much pressure could be applied. Further annealing of such tubes was required. After this treatment, total loads of 500,000 pounds could be applied without causing ruptures. Figure 1 shows the deformation accomplished on the new and on the old tubes.

For flowage tests of a year's duration chrome-nickel-steel spools of the type previously described[1] were used. In order to attain greater pressures in other tests, the thickness of the wall of the narrow part of the spool was increased from 0.3 to 0.4 and eventually to 0.5 centimeters. When tested, the steel spools did not prove of uniform strength, the strongest failing at a load of 167,500 pounds per square inch.

Pistons used in these experiments are ¾-inch in diameter and of white cast iron. They are the strongest, under straight compression, that can be obtained, withstanding a load of approximately 180,000 pounds per square inch.

Both the fracture and the flow type of experiments differ from previous tests only in the amount of pressure applied. In the fracture type of experiments, thickening the walls of the steel tubes from ⅛- to ¼-inch does not prevent the yielding of the container as the shale is deformed. The deformation accomplished at low pressures is essentially the same in both. At the higher pressures the deformation curve for the

[1]*Op. cit.*, p. 333.

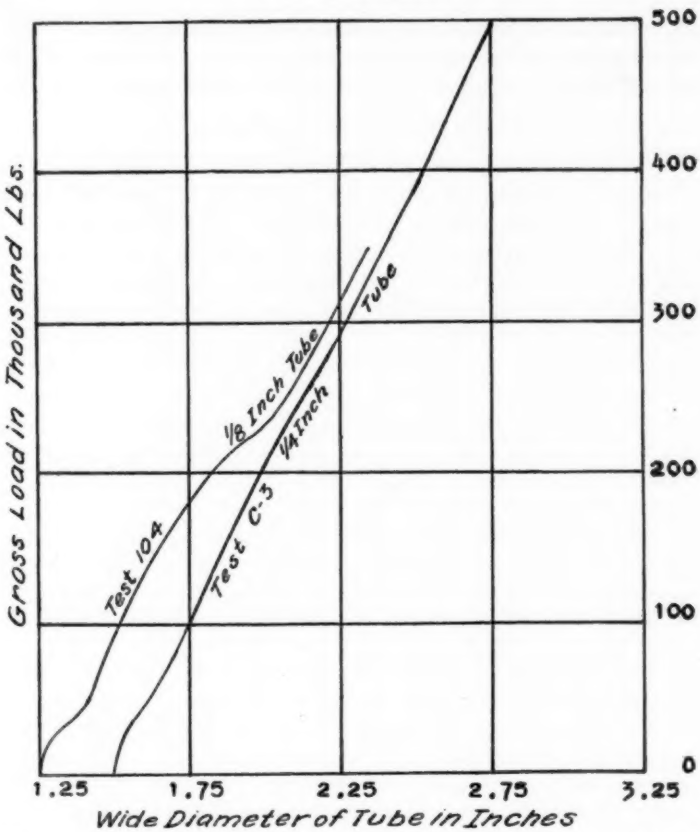

FIG. 1.—Deformation curves of Colorado shale in steel tubes of ⅛- and ¼-inch wall.

smaller-walled tube flattens relatively, and shearing is effected with slightly higher containing pressures in the thicker tubes.

In the flow type of experiments it is possible to so thicken the wall of the steel spool that it will not bulge, but by so raising the containing pressures on the shale, thereby strengthening it, the amount of pressure which can be applied, and the amount of cubic compression caused on the shale, are limited by the strength of the steel pistons. It is most probable that increasing containing pressures in this way would give an induced strength to the shale equal to that of the strongest pistons avail-

able. This is suggested by the fact that no cubic compression was effected on a core of cannel coal subjected to a load of approximately 136,000 pounds per square inch.

PROCEDURE IN THE SHEARING-PRESSURE TESTS

After the steel containers were loaded with shale or coal cores, or powder, pressures were applied in a hydraulic testing machine of 500,000 pounds capacity. The amount and time of deformation were recorded and the specimen removed from the container. The samples were then ground, some to pass an 80-mesh, and some a 300-mesh screen, as were comparable samples of unsheared rock. The soluble organic content of the samples was determined by extraction in Soxhlet extractors with purified chloroform. The period of extraction, unless otherwise noted, was 24 hours. The amounts of moisture and volatiles lost at 105°C. when the shale was dried for 6 hours in an atmosphere of nitrogen, were determined on separate samples. The percentage extract from each is based on the calculated dry weight of the material extracted. In Tables VII and VIII the percentage change in extract is calculated on the amount of extract from the unsheared sample.

PHYSICAL EFFECT OF SHEARING PRESSURES

The physical effects of high shearing pressures on oil shales encased in the heavy steel tubes are essentially the same as those described previously in tests in which lighter tubes were used. The shales yield largely by fracture. Open spaces in the interior were noticed in several specimens after sawing them in two, particularly where solid cores were used. Pressure on the powdered shale compacts it to a rigid block nearly as strong as the unbroken shale.

An interesting phenomenon occurs after the steel casing is entirely removed from the sheared core specimens. This is the elastic expansion of the shale which is illustrated in Figure 2. The expansion causes the opening up of many incipient fractures. How much of the increase in volume is due to the opening of the fractures and how much to actual expansion of the shale is difficult to ascertain. There seems little doubt, however, that the shale suffered some cubic compression in this type of experiment.

In the spool tests with heavier walls the shales yielded essentially by flowage and no incipient fractures were observed.

COLORADO OIL SHALE

Pressure tests on Green River oil shale from De Beque, Colorado, are summarized in Table VII.

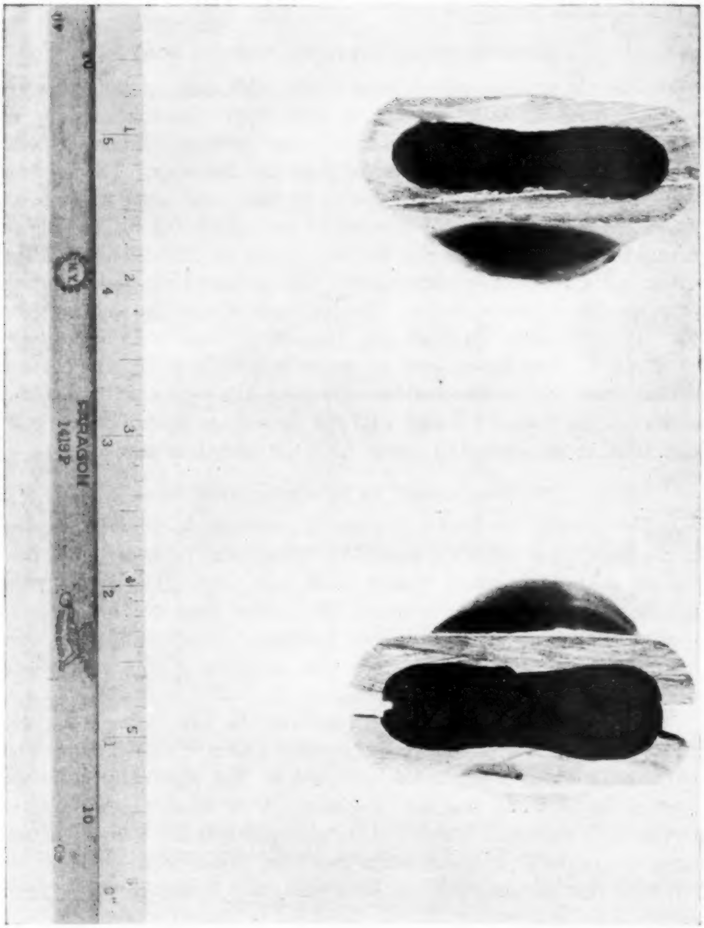

FIG. 2.—Photograph showing elastic expansion of Australian kerosene shale after removing steel tube. Shale core was subjected to a total load of 300,000 pounds, or 74,900 pounds per square inch (Test 6*T*).

TABLE VII

Test Number	*Load*	*Pounds per Square Inch*	*Moisture + Volatiles*	*Mesh*	*Per Cent Extract*		*Difference*	*Per Cent Difference*
					Unsheared	*Sheared*		
Pressure Tests with Heavy Steel Tubes								
C1U	Nil	Nil	.30	− 80	1.810			
C1	300,000	70,400	.23	− 80		1.808	−.002	−.11
C2U	Nil	Nil	.23	− 80	1.812			
C2	400,000	84,000	.24	− 80		1.780	−.032	−1.76
C3U	Nil	Nil	.31	− 80	1.952			
C3 (½)	500,000	91,250	.30	− 80		2.095	+.143	+7.3
C3U	Nil	Nil	.43	−300	2.12			
C3 (½)	500,000	91,250	.458	−300		2.23	+.11	+5.2

Recovery of Extract from Sands in Tube Tests

	Grams
C1	.0041
C2	.0061
C3	.0037

Test Number	*Load*	*Pounds per Square Inch*	*Moisture + Volatiles*	*Mesh*	*Unsheared*	*Sheared*	*Difference*	*Per Cent Difference*
1-Year Rock-Flowage Tests—Steel Spool Wall 0.3 Centimeter Thick								
CF5	Nil	Nil	.365	− 80	2.054			
CF5X	65,000	79,220	.365	− 80		2.042	−.012	−.58
CF6	Nil	Nil	.42	−300	1.865			
CF6X	65,000	79,220	.42	−300		1.839	−.026	−1.4
2-Hour Rock-Flowage Tests—Steel Spool Wall 0.4 Centimeter Thick								
	Nil	Nil	0.286	− 80	1.840			
CF4-1	73,500	167,500	0.222	− 80		1.868	+.028	+1.52
	Nil	Nil	0.24	− 80	1.920			
CF4-2	63,500	143,800	0.225	− 80		1.997	+.057	+2.97

EFFECT OF SHEARING PRESSURES ON COLORADO OIL SHALE

High shearing pressures on Colorado shale enclosed in steel tubes in two samples failed to cause an increase in the soluble organic content. In the third sample an appreciable gain in soluble matter was found. This increase, though close to the limit of experimental error, is still evident when both sheared and unsheared samples are reduced to -300-mesh before extraction. The effect of the fine grinding is to increase the recovery from both samples by an amount slightly greater than the

difference between the sheared and unsheared shale extracts. The effect of size of grain on extraction thus seems more important than has been noted in previous reports.[1] It is admitted, however, that the effect of fine grinding and increase of surface of the shale particles can not be distinguished from the effect of the shearing pressures employed in the grinding process. The negative differences in extracts from tests *C*1 and *C*2 are within the limits of experimental error. The average of the three tests indicates that the shearing pressures are not quantitatively important in converting the organic matter to a soluble form.

Extraction of the sands used in the three tube tests gave small recoveries of extract, suggesting a migration of some volatile organic matter from the shale to the sand during shearing. Further discussion is given following the description of the results of shearing tests on other oil shales.

The results of subjecting Colorado shale to a pressure of nearly 80,000 pounds per square inch in presses for 1 year, causing a slight flowage rather than severe fracturing of the shale, are negative. A fine grinding of the shales gives similar results. Previous tests already described[2] suggested that lengthening the time factor would increase still more the recovery of extract from the flowed shale. With pressures of 67,800 pounds per square inch, through differing periods of time, increases in extract noted previously were as follows.

Time	*Per Cent Extract of Shale*
71 days	+.04
109 days	+.02
7 months	+.21

The negative results of the year tests indicate that time, of the proportion used, is not important in aiding chemical reactions which might be induced by flowage pressures. Increased flowage pressures, attained by using thicker-walled steel spools, again seem to cause slight increases in the extract obtained from the flowed shale, but the increases are not proportional to the pressures used. They may be due to some cause directly or indirectly related to the pressure.

AUSTRALIAN "KEROSENE" SHALE

Pressure tests on diamond-drill cores of this shale are similar to those used for Colorado shale. The results of the tests are given in Table VIII.

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 311.

[2] *Ibid.*, p. 347.

TABLE VIII

SHEARING-PRESSURE TESTS ON AUSTRALIAN SHALE CORES

Test Number	*Load*	*Pounds Per Square Inch*	*Moisture + Volatiles*	*Mesh*	*Per Cent Extract*		*Per Cent Difference*	*Per Cent Change*
					Unsheared	*Sheared*		
Shale Sheared in Steel Tubes—Wall ¼ Inch Thick								
*6T**	300,000	74,900	.075	− 80		1.394 .996* .998 1.12 av.	+.294 −.104 −.102 +.02	+1.8
6TU	Nil	Nil	.105	− 80	1.10			
T (½) *TU*	350,000 Nil	86,100 Nil	.145 .13	− 80 − 80	1.057	1.338	+.281	+26.6
T (½) *TU*	350,000 Nil	86,100 Nil	.225 .23	−300 −300	1.188	1.125	−.063	−5.3
8T	400,000	78,400	.12	− 80		1.121 1.024* 1.318 1.154 av.	+.079 −.018 +.276 +.112	+10.0 av.
8TU	Nil	Nil	.15	− 80	1.042			
Flow Test—Wall of Steel Spool 0.4 Centimeter Thick								
FA4-1 *FAU*	52,500 Nil	118,900 Nil	.085 .095	− 80 − 80	1.135	1.272	+.137	+12.1
FA1†	47,000	106,000		− 80	1.03	1.10	+.07	+6.8
Flow Test—Wall of Steel Spool 0.5 Centimeter Thick								
FA5-1U	Nil	Nil	.28	− 80	0.987			
FA5-1X	62,500	141,466	.225	− 80		0.848	−.139	−14.1

Recovery of Extract from Sand in Tube Tests

Test	*Grams Extract*	*Approximate Per Cent 51-Gram Cores*
6T..	.0079	.015
T..	.0169	.033
8T..	.0071	.014

*Mechanical analysis given below.
†*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 351.

DISCUSSION OF RESULTS

The extraction results from Australian shale sheared with loads ranging from 74,900 to 86,100 pounds per square inch, and ground to -80-mesh, show that an increase of 1.8-26.6 per cent of the soluble matter is obtained from the sheared shales. The increases are approximately proportional to the loads exerted. The theory that the increases may be due, however, to the physical state of division of the sheared shale is supported by the data presented in Table II, where it is shown that a fine grinding of the unsheared shale causes a proportional increase, and by the fact that when both sheared and unsheared shales are ground to -300-mesh (Test *T*) the difference is eliminated. These arguments lack finality, inasmuch as fine grinding can not be done without the exertion of shearing pressures.

The extraction results of Test 6*T* show a large variation in content of extract from different parts of the same sheared core. This may be due to original differences in the cores or to changes produced during shearing. In Test *T*, fine grinding decreases the extract from the sheared sample 0.113 per cent. The decrease may be due to original differences in the shale, to loss of volatiles generated during the shearing, part of which may have been recovered in the sands, to loss of volatiles during the later fine grinding, or to oxidation of soluble compounds to form insoluble compounds in the last treatment. To ascertain which of these

TABLE IX

MECHANICAL ANALYSES OF SHEARED SHALES

Mesh	*Test 6T 300,000 Pounds*	*Test 8T 4,000,000 Pounds*
80–100	32.4	30.9
100–150	26.9	24.9
150–200	8.5	10.6
200–300	20.1	21.7
–300	12.0	11.9
Diameter in Millimeters Retained on Screen	*Test 6T, Cumulative Per Cent Retained*	*Test 8T, Cumulative Per Cent Retained*
0.147	32.4	30.9
0.104	59.3	55.8
0.074	67.8	66.4
0.046	87.9	88.1
–0.046	99.9	100.0

is the more important is not possible; therefore, definite conclusions as to the effect of shearing pressures can not be reached.

The recovery of extract in the sands is again noteworthy. In order to determine the relation between average size of grain and amount of extract obtainable from the sheared shales, mechanical analyses of parts of Tests 6*T* and 8*T* were made.

The results are shown graphically in Figure 3. The average texture of 8*T* is slightly finer than 6*T*, as shown by the variation in area below the curves. Actual extraction of these samples with chloroform gave: 8*T*—1.024 per cent, 6*T*—0.996 per cent, a difference of .028 per cent extract in favor of the finer shale.

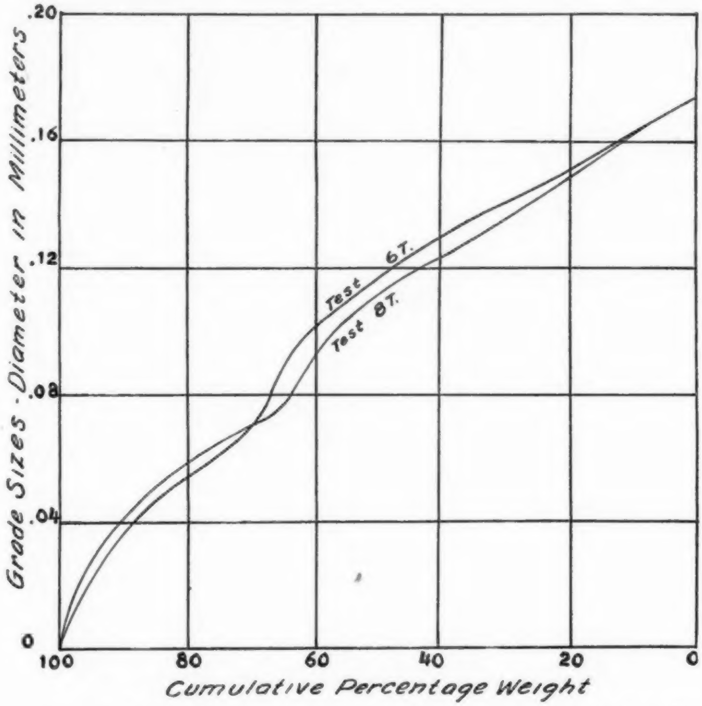

FIG. 3.—Cumulative curves showing mechanical constitution of Australian shale, Tests 6*T* and 8*T*, ground to pass an 80-mesh sieve.

In the "flow" test, an increase of 12.1 per cent of the soluble matter seems to be due to the load of 118,900 pounds per square inch. In such tests the shale yields mainly by flowage, and the effect of shattering in the tube tests is not nearly so noticeable. Some failure undoubtedly occurs by fracture, however, and the distinct increase may be accounted for either by this phenomenon or by the pressures themselves.

CANNEL COAL

Inasmuch as cannel coal is genetically related to oil shale and contains the same type of organic matter, experiments were made with it to test the effect of shearing pressures. A sample of cannel coal was received through the kindness of David White. The coal was collected from the mine of the East Kentucky Coal Company, at Lesley (Leslie), Kentucky, on the Big Sandy Division of the C. and U. Railway. The coal is described by White and Thiessen[1] as "black, tough, and somewhat slabby, splitting up into uneven slabs, one and a half to five or six inches in thickness, and distinctly conchoidal in oblique or vertical fractures." The analyses follow.

Air drying loss 0.40

Proximate Analysis		*Ultimate Analysis*	
Moisture	1.70	Sulphur	1.02
Volatiles	50.76–57.04	Hydrogen	6.83– 7.56
Fixed Carbon	38.23–42.96	Carbon	73.25–83.26
Ash	9.31	Nitrogen	1.31– 1.49
		Oxygen	8.28– 7.69

On extraction with chloroform, the coal yields about 2.5 per cent soluble matter, the greater part of which is readily dissolved in the first few hours. An extraction test with chloroform on a sample ground to -80-mesh gave the following.

	Per Cent Extract
1st 24 hours	2.236
2nd 24 hours	0.169
3rd 24 hours	0.097
4th 24 hours	0.062
Total per cent in 96 hours	2.564

Table X shows that the losses on drying the unsheared coal samples at 105°C. are consistently greater than the losses from the sheared samples. This may be accounted for by a loss of volatiles during shear-

[1]David White and R. Thiessen, *U. S. Bur. Mines Bull. 38*, pp. 44, 47, 253-58.

ing, some of which are retained in the sand. In all three tests the sheared shale, on extraction, yielded 5-10 per cent more soluble organic matter when the samples were ground to pass an 80-mesh screen. When samples CC_1 and CCU_1 were ground to -300-mesh, however, the difference of +5.7 per cent was reduced to +1.4 per cent. The exact time of extraction

TABLE X

SHEARING-PRESSURE TESTS IN STEEL TUBES WITH ¼-INCH WALLS

Test Number	*Gross Load*	*Final Load in Pounds per Square Inch*	*Moisture + Volatiles 105°C.*	*Per Cent Extract*		*Per Cent of Coal Difference*	*Per Cent Difference of Extract*
				Unsheared	*Sheared*		
CC_1	300,000	83,100	0.604		2.60	+.14	+5.7
CCU_1 80-mesh	Nil	Nil	0.767	2.46			
CC_1 −300-mesh	300,000	83,100	.736		(1) 3.057 (2) 3.293†	(1) +.042* (2) +.055	+1.4 +1.7
CCU_1 −300-mesh	Nil	Nil	1.064	(1) 3.015* (2) 3.238+			
CC_2	400,000	92,500	0.52		2.68		
CCU_2 80-mesh	Nil	Nil	0.827	2.435		+.245	+10.1
CC_3	500,000	103,000	0.485		2.61		
CCU_3 80-mesh	Nil	Nil	0.775	2.41		+.20	+8.3

EXTRACTS FROM SAND IN SHEARING-PRESSURE TESTS

Test Number	*Grams Extract*
CC_1	.0022
CC_2	.0042
CC_3	.0038

*First figure—time extraction over 24 hours; heater burned out in night.

†Second figure—total per cent extract after a further period of 24 hours' extraction.

in the latter experiment was not known, but it is probable that the finer grinding increased the rate of solution of the organic matter over that of the coarser-grained coal. If both samples were ground to identical sizes it is probable that the remaining difference would be eliminated entirely. Further discussion of this subject is given in the discussion of results.

CANNEL COAL-FLOWAGE TESTS

Flowage tests on drill cores of cannel coal, ¾inch in diameter, were made with chrome-nickel-steel spools. In Test 1 the wall of the spool was 0.4 centimeter thick; in the others, 0.5 centimeter. In Test 2 the volume of the coal core was measured carefully by immersion in mercury before and after flowage. Essentially no change in volume occurred, though the coal flowed laterally 0.13 inches. In Test 3 coal of -80-mesh was first extracted for 24 hours with chloroform and a part was then subjected to flowage pressure. The results are shown in Table XI.

TABLE XI

Test Number	*Load in Pounds per Square Inch*	*Moisture + Volatiles 105°C.*	*Per Cent Extract*	*Difference*	*Per Cent Change*
1 1*U*	147,500 Nil	.0630 .0666	2.71 2.34	+.37	+15.8
2 2*U*	135,885 Nil	1.105 1.045	2.39 2.19	+.20	+ 9.14
3*U*	Nil	.91	1st 24 hours 2.29 2nd 24 hours 0.27 2.56		
3*U* 3	Nil 140,750	.91	1st 24 hours 2.29 2nd 24 hours .424 2.714	+.154	+ 6.01

The increase in soluble matter in Test 3 is close to the limit of experimental error. The increase in all these samples may perhaps be related to physical as well as to chemical changes brought about by pressure. It is interesting to notice in Test 3 that an increase was still obtained in extract from coal sheared after the larger amount of soluble organic matter was removed. The experiment does not indicate the nature of the change accomplished by the pressure.

INDIANA OIL SHALE

A sample of oil shale was received through the kindness of Robert S. Shrock from the New Albany shale, Indiana. Tests were made of

both the fracture and flow type. In the former, steel tubes with ¼-inch wall were used with shale crushed to pass a 20-mesh screen. In the latter, steel spools with a wall 0.5 centimeter thick encased either a solid core of shale or crushed shale. The results of the tests are given in Table XII.

DISCUSSION OF RESULTS

In the "fracture" tests the per cent extract obtained from the sheared Indiana shale was from 26 to 38 per cent greater than from the unsheared shale. When the samples were ground to -300-mesh this difference was decreased by only 3-4 per cent. The fine grinding caused very little increase in extract from the unsheared shale, and a seeming decrease in the extract from the sheared shale. In Test No. *I3*, more prolonged extraction of the two samples, for 48 hours, caused a reduction in the difference to +14.6 per cent of the extractable matter. It is clear that size of grain is not as important in this shale as in others in accelerating the rate of solution. It is possible that the shearing has rendered the soluble organic matter more soluble, or that insoluble organic matter has been altered chemically to a soluble form. Further tests should be made to determine the difference in extract when extraction is carried on for much longer periods of time. If the difference can be still further reduced, it is probable the change resulting from the shearing is a physical rather than a chemical one. The noteworthy increases in soluble organic matter after shearing do not seem attributable to effects of oxidation, as previously shown.[1]

The small amounts of extract obtained from the sands used with the sheared shale here again suggest a transfer of organic matter from the shale to the sand during shearing. It is possible some of the extract may be accounted for by contamination with the powdered shale used in the tubes, especially since the amounts do not correspond with the pressures.

The flowage tests in this shale again show an appreciable increase in soluble organic matter; approximately the same increase is obtained even if the easily soluble organic matter is first removed by extraction before the shearing pressures are applied. Altogether this shale gives outstanding results; the marked increases in soluble organic matter after shearing, as far as is known, are not attributable to any factor other than the pressures applied.

KENTUCKY OIL SHALE

Further shearing-pressure tests of the fracture type have been made on Chattanooga (Upper Devonian) oil shale from Kentucky. The steel

[1] pp. 458-59.

TABLE XII

"FRACTURE" TESTS—NEW ALBANY, INDIANA, SHALE

SHALE GROUND TO -80-MESH

Test Number	Pounds	Load in Pounds per Square Inch	Moisture + Volatiles Per Cent of Natural Shale	Per Cent Extract		Differ-ence	Per Cent Change
				Un-sheared	Sheared		
I	Nil	Nil	1.03	2.075 2.24 Av. 2.158			
I1	300,000	77,900	.95		2.817	+.659	+30.7
I2	400,000	88,800	.78		3.018 2.933 Av. 2.975	+.817	+37.9
I3	500,000	104,500	.745		2.90	+.742	+34.4

TEST NO. I-1 AND I-3—SHALE GROUND TO -300-MESH

Test Number	Pounds	Load in Pounds per Square Inch	Moisture + Volatiles Per Cent of Natural Shale	Un-sheared	Sheared	Differ-ence	Per Cent Change
I	Nil	Nil	1.445	24 hours 2.21 48 hours 2.597			
I3	500,000	104,500	1.595		24 hours 2.68 48 hours 2.98	+.47 +.383	+21.3 +14.8
I	Nil	Nil	1.49	2.176			
I1	300,000	77,900			2.745	+.569	+26.2

FLOWAGE TESTS ON INDIANA SHALE

Test Number	Pounds	Load in Pounds per Square Inch	Moisture + Volatiles Per Cent of Natural Shale	Un-sheared	Sheared	Differ-ence	Per Cent Change
IF1	Nil 51,000	Nil 116,000	2.13 2.82	2.06	2.38	+.32	+15.5

SHALE FIRST EXTRACTED, THEN SHEARED

Test Number	Pounds	Load in Pounds per Square Inch	Moisture + Volatiles Per Cent of Natural Shale	Un-sheared	Sheared	Differ-ence	Per Cent Change
IF2	Nil	Nil	2.60	1st 24 hrs. 2d 24 hrs.	1.73 .552 2.282		
	62,000	140,330	3.84	2d 24 hrs.	.900	+.348	+15.3

RECOVERY OF EXTRACT FROM SANDS

Test Number	Grams Extract
I1	.0058
I2	.0038
I3	.0018

tubes used have a ¼-inch wall. In these, powdered shale of -35-mesh was packed and sheared as in other tests. Before extraction of the samples they were ground to -80-mesh, and one to -300-mesh. The results are given in Table XIII.

TABLE XIII

KENTUCKY CHATTANOOGA OIL SHALE

Test Number	Load	Load in Pounds per Square Inch	Moisture + Volatiles 105°C.	Mesh	Per Cent Extract		Difference	Per Cent Change
					Sheared	Unsheared		
STEEL TUBE—⅛-INCH WALL								
302*	200,000	87,000	.71	− 80	0.688	0.63	+.058	+9.2
303*	250,000	81,700	.71	− 80	0.65	0.63	+.02	+3.2
STEEL TUBE—¼-INCH WALL								
K	Nil	Nil	.145	− 80		0.799		
3*K*	300,000	92,400	.66	− 80	1.14		+.351	+44.0
2*K*½	400,000	105,600	.76	− 80	0.930		+.141	+14.3
1*K*	500,000	113,100	.73	− 80	0.870		+.81	+10.2
K	Nil	Nil	.943	−300		0.918		
2*K*½	400,000	105,600	.968	−300	.912		−.006	−.65

EXTRACT FROM SANDS

Test Number	Grams Extract
3*K*	.0065
2*K*	.0078
1*K*	.0077

**Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 352.

DISCUSSION OF RESULTS

In all experiments where Kentucky shale was sheared, ground to -80-mesh, and extracted, the amount of extract obtained was greater than that from the unsheared shale. In the tests with heavy steel tubes, the increase in extract is appreciable, in some tests being as much as 40 per cent of the soluble matter. The differences, however, vary inversely as the pressure applied to the shale. The unsheared shale shows the greatest loss of moisture and volatiles at 105°C., but this should not affect the extraction results, as this loss is determined in each test on separate samples. Whenever the sheared and unsheared shales are ground to -300-mesh, as in Test 2*K*, the difference in percentage extract dis-

appears. In this test the fine unsheared sample yields more soluble matter than that of coarser grain, and again the sheared sample shows a slight decrease in extract. The sands from the three tests gave small amounts of extract after shearing. The amount is of the same order of magnitude as that recovered from other shale-sands. The extract may be due to contamination with the powdered shale used in these tests, though every care was taken to avoid this. Similar recoveries from sands used with other solid shale cores suggest that some of the more volatile organic matter has been driven off to the sand.

CLEVELAND, OHIO, DEVONIAN OIL SHALE

A sample of the Devonian oil shale from Cleveland, Ohio, previously tested, was sheared in 7-inch steel tubes with ¼-inch walls in the same manner as other shales. All samples were afterward ground to pass an 80-mesh screen and extracted with chloroform for 24 hours. The results are shown in Table XIV.

TABLE XIV

Test Number	*Load*	*Pounds per Square Inch*	*Moisture + Volatiles*	*Per Cent Extract*		*Difference*	*Per Cent Change*
				Unsheared	*Sheared*		
STEEL TUBE—⅛-INCH WALL							
400*	Nil	Nil	.45	0.25			
401	200,000	66,000	.45		0.24	−.01	−4.0
STEEL TUBE—¼-INCH WALL							
*CLU*1	Nil	Nil	.55	0.322			
*CLX*1	300,000	92,000	.628		0.358	+.036	+11.2
*CLX*2	400,000	106,400	.622		0.323	+.001	+ 0.31
*CLX*3	500,000	116,200	.60		0.357	+.035	+10.9

RECOVERY OF EXTRACT FROM SANDS

Test Number	*Grams of Extract*
*CLX*1	.0052
*CLX*2	.0084
*CLX*3	.0042

**Bull. Amer. Assoc. Petrol. Geol.*, Vol 13 (1929), p. 353.

DISCUSSION OF RESULTS

The effect of shearing the Cleveland shale is similar to that found in other shales. Though all the recent tests show an increase in the extract

from sheared shales, the amounts are small and the experimental error is correspondingly high. The increase in soluble organic matter may again be related to the more finely divided or shattered nature of the sheared shale, or to some chemical change. Two samples, however, show practically no increase. The recovery of small amounts of extract from the sands with which the shales were sheared suggest the expulsion of this material from the shale during shearing. The extract, entire or in part, may be due to contamination with the powdered shale used.

MANCHURIAN OIL SHALE

A sample of oil shale from Manchuria was obtained from Mr. Sakamoto, a graduate student at the University of Wisconsin. The shale is in the form of drill cores, 2 inches in diameter and ranging from ½ to 1 inch thick. A composite sample was taken from the richer pieces and was powdered to pass a 35-mesh sieve. The pressure tests consisted of shearing three lots of the shale encased in steel tubes with ¼-inch walls, the shale being packed with sand as in other experiments. The samples were afterward ground to -80-mesh and extracted for 24 hours with chloroform. One-half of one sheared specimen was also ground to -300-mesh and extracted. The results are given in Table XV.

TABLE XV

Test Number	*Load*	*Pounds per Square Inch*	*Moisture + Volatiles*	*Mesh*	*Per Cent Extract*		*Difference*	*Per Cent Change*
					Unsheared	*Sheared*		
J	Nil	Nil	1.34	− 80	0.713			
J3	300,000	78,200	1.64	− 80		0.752	+.039	+ 5.5
J2	400,000	90,000	1.62	− 80		0.807	+.094	+13.2
J1	500,000	97,100	1.39	− 80		0.817	+1.04	+14.6
J1	500,000	97,100	2.14	−300		0.730	+.010	+1.4
JU	Nil	Nil	2.04	−300	0.720			

RECOVERY OF EXTRACT FROM SANDS

Test Number	*Grams Extract*
J1	.0023
J2	.0032
J3	Lost

DISCUSSION OF RESULTS

Shearing pressures cause a seeming increase in the soluble organic matter of the Manchurian oil shale. The increase varies directly, though

not proportionally, with the pressures applied. One-half of Test *J1*, which showed a 14.6 per cent increase, when ground to -300-mesh yields practically the same extract as that obtained from a similarly treated sample of unsheared shale. The former difference is equalized largely by a decrease in percentage extract from the sheared shale and a slight increase in that from the unsheared shale. All of the extracts from the sheared specimens are greater than that from the -300-mesh unsheared sample, which indicates that the shearing, whether it produces a physical or a chemical change in the shale, is more effective than grinding the shale from -80- to -300-mesh.

With this shale, also, slight recoveries of extract from the sands encased with the shale during shearing are to be observed.

GILSONITE FROM UTAH

Through the kindness of C. G. Maier, of the United States Experiment Station, Berkeley, California, a sample of gilsonite was obtained from Utah. The gilsonite is black, and brittle, is slightly soluble in cold alcohol, and on extraction with chloroform for 24 hours yields about 17 per cent soluble matter. An X-ray photograph of powdered gilsonite showed it to be entirely amorphous.

A sample was crushed to pass a 20-mesh sieve and two pressure tests were made. In these the gilsonite was packed in short steel cylinders, 1½ inches long and 1 inch in inside diameter. Copper plates were placed at the ends of the cylinder and the pressure was applied parallel with the long dimension of the tube as in tests previously described.[1] After shearing, the gilsonite was removed from the tubes, powdered to -20-mesh size, and extracted with chloroform for 24 hours. Difficulty was presented in grinding the material to a uniform small size, because under pressure it becomes sticky and fine grinding is not possible. The difficulty was partly overcome by freezing the material at frequent intervals. The results of the tests are shown in Table XVI.

TABLE XVI

Test Number	*Load*	*Pounds Per Square Inch*	*Per Cent Extract*	*Difference*	*Per Cent Increase*
CU	Nil	Nil	17.18		
CK1	300,000	150,000	17.79	+.61	3.55
CK2	300,000	225,100	17.81	+.63	3.67

[1]*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), p. 332.

After shearing, the gilsonite yields slightly more soluble extract than before. The differences are slight and within the limit of experimental error. The increased solubility may be due to differences in the size of grain of the sheared and the unsheared material, as well as to any chemical changes induced by the pressure.

SUMMARY OF RESULTS OF SHEARING-PRESSURE TESTS

Table XVII summarizes the results of recent pressure tests. In all but three of twenty-three fracture-type experiments the extract obtained from the sheared shales is greater than from unsheared samples. The most marked increases are found in the Indiana, Kentucky, and Australian shales. In all the tests, whether powdered or solid shale cores were used, some extract was recovered from the sands used with the tests. In only one test (with a Manchurian shale), however, does the increase in extract vary directly with the pressures. In the sand recoveries the extracts do not vary with the pressures used. Finer grinding of the sheared and unsheared samples invariably decreases the difference in extract, but appreciable differences are still found in the Indiana and Colorado shales. In the others so tested, the gain in extract by the sheared shales is wholly or partly eliminated by increase in the amount of extract from the unsheared, and decrease in extract from the sheared shales. With the exception of the year tests on Colorado shale, the flowage experiments show a small increase in extract for the flowed Colorado shale and more marked increases for the Australian shale and cannel coal.

Discussion of Results and Conclusions

That high shearing pressures cause some change in the shales and coal tested is clear, but whether this change is real or seeming, and whether purely physical, purely chemical, or both, is difficult to ascertain. The percentage change in the soluble organic matter extracted from 80-mesh sheared shales differs considerably for different tests on the same shale and for the different shales. As the increase in extract generally is not proportional and does not vary directly with the pressures applied, it seems probable that the changes are more seeming than real. In so far as the amount of extract dissolved in a specified time is a function of the surface exposed to the solvent, and as the sheared shales are potentially more finely divided than the unsheared samples, the increase in extract from the former may be related, ordinarily, to a difference in physical state. For most of the shales, though unsheared, fine grinding alone causes an increase in extract. In some, this increase

TABLE XVII

SUMMARY OF RESULTS OF SHEARING-PRESSURE TESTS

Material	*−80-Mesh Shale Increase in Extract from Sheared Shale*	*Proportional to Pressure*	*−300-Mesh Shale Increase Maintained*	*Increase Eliminated by Fine Grinding*	*How Eliminated*	*Extracts from Sands*	*Increase in Extract Flow Test*
Colorado shale, solid core	In 1 of 3 +7.3 per cent Negative in 2	No	Yes +5.2 per cent	Partly	Increase from unsheared shale	Yes	+1-3 per cent in 2 tests Negative in 2 tests
Australian shale, solid cores	In all 1.8-26.6 per cent	No	No	Yes	Increase, unsheared. Decrease, sheared	Yes	Yes, 6.8-12 per cent
Cannel coal, solid cores	In all 5-10 per cent	No	Slight	Largely to 1.4 per cent	?	Yes	Yes, 15.8 per cent
Indiana shale, powdered	In all 30-38 per cent	No	Partly	Partly to 14.8-26.2 per cent	Slight increase, unsheared	Yes	Yes, 15.3 per cent
Kentucky shale, powdered	In all 3.2-44 per cent	No	No	Yes	Increase, unsheared. Slight decrease, sheared	Yes	No test
Cleveland shale, powdered	0.3-11.2 per cent Negative in 1	No	No test	No test	No test	Yes	No test
Manchurian shale, powdered	In all 5-14 per cent	Yes	Slight	Largely to 1.4 per cent	Increase, unsheared Decrease, sheared	Yes	No test
Gilsonite	Slight						

is proportional to that produced by high shearing pressures; in others it is less. Though it is admitted that fine grinding and exertion of high shearing pressures are inseparable, the shales which were sheared and also ground to -300-mesh, suffered more, or longer continued, pressures than those ground only to this size. Hence, if the pressure itself caused a chemical change, the differences in extracts should all be maintained in spite of the fine grinding. The only shales behaving in this way are those from Colorado and Indiana, and of these only the differences again observed for the Indiana shale are important. The increases in extract from sheared samples of this shale are greater than those of any other shale. The differences are not proportional to, nor do they vary with, the pressures applied. They do not seem related to purely physical changes in size of shale particles produced by the pressure. They are clearly not to be accounted for wholly by any oxidation occurring during the shearing. A possible alternative is that the pressures aided a chemical reaction in which soluble compounds were produced from insoluble organic matter, though definite proof of this is still lacking.

The results of grinding some sheared shales to -300-mesh are peculiar in that the per cent extract is decreased considerably. Possible causes given are: (1) original differences in shale samples, (2) irregular loss of volatiles generated during shearing or fine grinding, (3) oxidation of soluble compounds to form insoluble compounds during the prolonged fine grinding. The opportunity for loss of volatiles or oxidation of the shale is greater in grinding the shale to -300-mesh than in reducing it only to -80-mesh. If the decrease is caused by the second or third factors, the results of the fine grinding can not be considered as eliminating the differences between sheared and unsheared shales. Comparing -300-mesh unsheared Australian shale (Test *TU*) and the -80-mesh sheared shale (Test *T*), an increase of 12.7 per cent extract would still be maintained for the sheared shale. If, however, it be admitted that the physical effect of great shearing pressures is more pronounced than the simple grinding, such increases would be expected. It is thus difficult to reach any satisfactory conclusion at the present stage of the work, but it is evident that, except in regard to the Indiana shale, the burden of proof rests still on the assumption that shearing pressures cause a chemical change in the organic matter by generating more soluble compounds, as similar results may be gained by purely physical phenomena.

The same conclusion applies to the fact that small recoveries of extract were obtained from the sands used in the tests. Every precaution was taken to prevent contamination of the sands with shale particles.

In tests with powdered shales, this was difficult, but the consistent results suggest that the extract is due to the migration of slight amounts of soluble organic matter from the shale to the sand. The relation of the recovered extract to the pressures is as follows.

Indiana shale	Varies inversely as pressure
Australian shale	Greatest recovery with greatest pressure
All others	Greatest recovery with intermediate pressure

As noted in earlier papers, the amount of fluid which theoretically migrates from a shale during shearing must depend on the dilatant properties of the shale, on the changes in fluid pressures induced within the shale, and, in the individual tests, on the air-tightness of each tube. The fact that most of the sands yielded the greatest extract from tests with the 400,000-pound load suggests a relation to the dilatant behavior of the shales. Reduction of volume by elimination of pore space or volatiles may occur first, up to a given point; further deformation by fracture and concomitant increase in volume or reduction of fluid pressures would cause any migrant fluids to pass in the opposite direction, thus reducing the amount originally in the sands. This explanation fits for the Indiana shale as well as for the average, as the greatest decrease in volume by the packing of this shale, which was powdered, may have occurred with the 300,000-pound load.

The migration of organic matter from the shales to the sands, however minute, and whatever the exact cause, is significant in explaining natural occurrences with respect to oil, and in supporting White's[1] conclusions regarding the devolatilization of coals by shearing pressures. With pressures of earth magnitude this effect may become appreciable. Laboratory results, however, do not indicate the effect as quantitatively important, compared with heat.

The results of flowage tests are perhaps more significant than others, in that the possible influence of shattering and fracturing of shale particles must be less pronounced. The differences in extracts from flowed and unflowed specimens are important only in connection with shales from Australia and Indiana, and cannel coal. The increases in extracts from sheared Indiana shale and cannel coal (15 per cent) are well above the limits of experimental error. In these it is possible some chemical reaction may have occurred, but it has not been possible to distinguish the effects of such a reaction from similar effects due only to physical causes. Quantitatively, the effect of flowage pressures can not be con-

[1]David White, *Amer. Inst. Min. Met. Eng.*, Vol. 71 (1925), pp. 253-81.

sidered great, and it has not yet been shown that much of the organic matter of the shales may be so altered to soluble forms.

Summary of Conclusions

Additional shearing-pressure tests at room temperatures on oil shales from Colorado, Australia, Indiana, Kentucky, Cleveland, and Manchuria, and on cannel coal from Kentucky, all failed to generate oil. Nearly all the tests, however, show that more soluble organic matter may be extracted from the sheared than from unsheared specimens. The increase is believed due mainly to the finer physical state of the highly sheared shale, rather than to any chemical reactions caused by pressure. It is possible that the Indiana shale is an exception to this conclusion. This shale shows the most marked increases in soluble organic matter after shearing. The change can not be wholly related to physical effects of pressure, nor to the effect of oxidation, and while it may be due to a chemical reaction, no positive evidence for such has been obtained.

From all the sands used with shale or coal being sheared, small recoveries of extract were obtained. The extract seems related only to a change in physical state and migration of the more volatile constituents from the shales to the sands. The migration of the material and consequent devolatilization of the shale or coal is significant in regard to some natural occurrences, and supports White to some extent in his conclusions regarding the cause of loss of volatiles from coal beds.

The flowage tests completed show that in some samples the flowed shale or coal yields more soluble organic matter on extraction. These increases are not so easily related to purely physical changes caused by the pressure. Also, chemical reactions, induced by the pressures, may be of some importance.

Former conclusions, that quantitatively the effects of shearing pressure exerted at room temperatures on oil shales or related rocks are not important in converting the organic matter to oil or to more soluble form, still hold true, as compared with the effect of heat. Shearing pressures, however, do cause an increase in the soluble organic matter of such rocks, and though this change may ordinarily be related to physical causes only, the effect can not altogether be neglected.

EXPERIMENTS RELATING TO SALT-DOME STRUCTURES[1]

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ABSTRACT

The description and illustration of a series of laboratory experiments which were originally designed for the reproduction of miniature igneous intrusions are offered as suggestive material relating to the study of salt-dome structures. Graded materials, ranging from rigid to fluid, were injected from below into artificial sediments. Only such features as developed and were observed repeatedly are enumerated and suggested for consideration.

INTRODUCTION

The many excellent contributions concerning American and foreign salt-dome structures which have appeared in this *Bulletin* and the assemblage of most of these papers in the well known volume *Geology of Salt Dome Oil Fields* have afforded a reliable and convenient source of information on this interesting subject. As a result of these publications it is possible for those not actually engaged in salt-dome field geology to obtain a graphic picture of the nature of such uplifts. The writer of this paper has had no field experience connected with salt domes; nevertheless, the papers referred to have led him to believe that an account of the results of several laboratory experiments might be useful. Although these experiments were performed with the object of simulating the intrusion and extrusion of igneous rocks,[3] it nevertheless seems appropriate to call the attention of salt-dome specialists to those results which may have a bearing on their problems.[4]

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, February 5, 1930.

[2]Geologist, Imperial Oil, Ltd.

[3]R. T. Chamberlin and T. A. Link, "The Theory of Laterally Spreading Batholiths," *Jour. Geol.*, Vol. 35 (1927), No. 4.

[4]Previous publications of a similar nature which are known to the writer are the following: Eduard Reyer, *Geologische und Geographische Experiments*, II. Heft, "Vulkanishe und Masseneruptionen" (Leipsig, 1892); G. Linck, *Neues Jahrb. für Min. und Geol.*, Festband (1907), S. 91; G. R. MacCarthy, "Some Facts and Theories Concerning Laccoliths," *Jour. Geol.*, Vol 33, No. 1 (1925); P. D. Torrey and C. E. Fralich, "An Experimental Study of the Origin of Salt Domes," *Jour. Geol.*, Vol. 34, No. 3 (1926); B. G. Escher and Ph. H. Kuenen, "Experiments in Connection with Salt Domes," *Leidsche geologische Mededeelingen* (1929), Deel III, Aflevering 3, II, pp. 151-82 (reviewed by Donald C. Barton in *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 107-08.

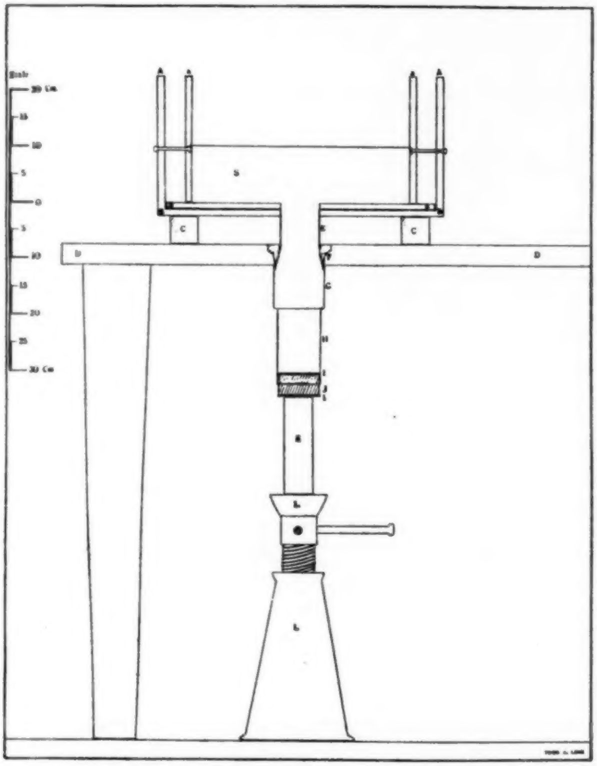


FIG. 1.—Cross-sectional drawing of apparatus used to force rigid, mobile, and fluid masses into artificial strata.

A, permanent sides of box; *a*, removable sides of box; *B*, permanent floor of box; *b*, removable floor of box; *S*, artificial strata; *D*, table-top; *E*, 2½-inch iron nipple or pipe; *F*, reducing bushing screwed to table-top; *G*, 3½-inch iron collar separable from *F*; *H*, 3½-inch iron nipple; *I*, rubber packers on wooden plunger *J*; *K*, wooden block; *L*, iron jack-screw.

The scale is shown graphically.

Courtesy of *Imperial Oil Review* (Toronto, April, 1929).

DESCRIPTION OF EXPERIMENTS

APPARATUS

The apparatus used in performing most of the experiments described in this paper is illustrated and explained in Figure 1. The entire apparatus was securely bolted to a laboratory table-top. The finished models

were lifted out of the box on the false floor *b*, photographed, and studied in ground plan. Molten paraffine was then poured into all open surficial fissures to strengthen the models, after which they were cut by means of a cross-cut saw, and the sections photographed and studied.

EXPERIMENT 8 (FIGURES 2 AND 3)

In Experiment 8 three layers of fine-grained sand mixed with plaster, separated by thinner layers of pure plaster of Paris, were in-

TABLE I

RECORD OF SEDIMENTS

Stratum	*Kind of Material*	*Proportions in Kilograms*	*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	Loose sand	....	13.50	7.20
Blotter	Blotting paper	....	....	....
Plaster No. 3	Plaster Water	0.53 1.23	1.76	0.50
Sand No. 3	Sand Plaster Water	7.43 0.60 1.70	9.73	3.20
Plaster No. 2	Plaster Water	0.53 1.23	1.76	0.30
Carbon Seam	Slight amount of carbon	0.10	....	....
Sand No. 2	Sand Plaster Water	6.75 0.53 1.65	8.93	3.45
Plaster No. 1	Plaster Water	0.45 1.23	1.68	0.25
Sand No. 1	Sand Plaster Water	5.10 0.62 2.02	7.74	3.80
Total (plus overburden)			45.20	18.70
Total (minus overburden)			31.70	11.50

Duration of intrusion........................ 3 minutes (approximately)
Maximum uplift (height).................... 3.6 centimeters
Diameter of intruded cylinder............... 6.25 centimeters
Area of uplift (diameter)....................20.00 centimeters
Material injected, rigid cylinder of plaster of Paris

truded from below by a rigid, flat-topped cylinder. Above the upper plaster layer an overburden of loose sand was placed before the intrusion of the cylinder. Table I is a complete record of the materials used and their weights.

The results are well shown in Figures 2 and 3. The first manifestation at the surface was a pronounced peripheral hinge-break accompanied

FIG. 2.—Surface map, or top view, of Experiment 8. Notice the wide concentric or peripheral tension fissures and the less important radial tension fissures on the domal uplift. The outermost concentric break is the surface trace of the major upthrust fault. The scale in this and succeeding figures represents 15.2 centimeters or 6 inches. Courtesy *Imperial Oil Review* (Toronto, April, 1929).

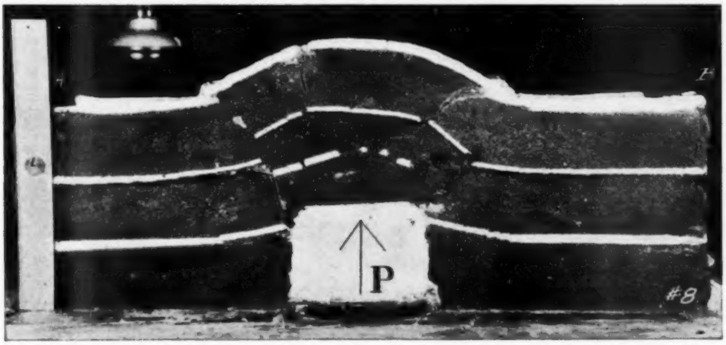


FIG. 3.—Section cut through center of Experiment 8. *P* is the rigid plaster of Paris cylinder forced into the sediments from below. Notice the bowl-in-bowl arrangement of the upthrust fault planes. Tension fissures are apparent in all brittle layers of the dome and seem to have no connection with one another from layer to layer. Courtesy *Imperial Oil Review* (Toronto, April, 1929).

by radial tension fissures. The inner peripheral, or concentric, break also relieved tension. However, further intrusion of the solid cylinder caused the formation of five master tension fissures radiating outwardly from the innermost concentric break, with many smaller additional radiating tension fissures. The succeeding outermost concentric break marked the maximum development of the dome, and after its formation the deep bowl-shaped mass, bounded by an upthrust fault plane, was lifted by the upward-moving cylinder (Fig. 3). It is interesting to notice that a third peripheral or concentric break had developed faintly, but the material was not coherent enough to lift away at such a distance from the center. A closer examination of Figure 3 also reveals radial and concentric tension breaks in the lower layers, and the final thrust fault plane is shown by the paraffine which was poured in from the top and allowed to occupy the fractures in which it cooled and solidified.

EXPERIMENT 11 (FIGURES 4 AND 5)

Into a series of sediments of the same nature as those of Experiment 8 a fairly fluid mud was intruded. The size of the opening through which the mud was injected was the same as the diameter of the solid cylinder. An overburden of the same weight was also placed over the sediments. The duration of this experiment was two minutes. The height of the maximum uplift was 2.10 centimeters, and the diameter of the resulting dome was 25 centimeters.

When the intrusion began the mud made some headway in forcing its way upward, but managed to find an outlet along the linoleum false bottom, and spread underneath it in the shape of a thin sheet. However, the results of the experiment were gratifying in exhibiting the initial stages of an intrusive mass of this sort. The surface manifestations of this intrusion are shown in Figure 4 and exhibit an excellent example of a single master and two subsidiary tension fissures and two peripheral or concentric breaks. The cross section (Fig. 5) shows that no conspicuous fault breaks had occurred, and that merely a broad dome, with a master tension fissure cutting across it, had developed. This experiment suggests that the fluidity or viscosity of the intrusive material is an important factor in the nature of the structure developed.

EXPERIMENT 21 (FIGURES 6 AND 7)

An attempt was made to bring in the factor of gas pressure accompanying igneous intrusions, and for this purpose the following method was used in Experiment 21. Carbide was placed in the bottom of

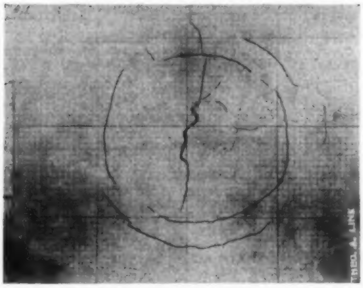


FIG. 4.—Map showing tension fissures developed on top of dome in Experiment 11. Notice the jagged, master tension fissure and the concentric fissures.

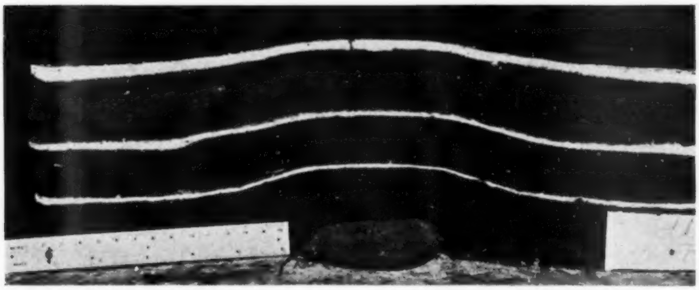


FIG. 5.—Cross section cut through center of Experiment 11, illustrating incipient arching of strata by intrusion of a plastic mud. Notice single tension fissure in upper layer.

pipe *H* (Fig. 1) and above it a chamber of water, sealed off above and below by a thin layer of paraffine. Above the water was placed some fairly thin plastic mud. Essentially the same artificial sediments as employed in Experiments 8 and 11 were again employed, but *no overburden of loose sand was used.*

Upon application of pressure the partition between the carbide and the water was broken, causing the formation of a large volume of gas. The piston *J* was pushed upward by means of a jack-screw. It soon became evident that the gas had very little to do with the uplifting of the sediments, but disseminated through the porous sand layers, and, upon reaching the first plaster layer, migrated beneath it to the edges of the box, where it escaped. The actual uplifting and formation of the

surficial tension cracks were accomplished wholly by the upward-moving mud near the close of the experiment (Figs. 6 and 7). The mixing of some of the remaining water with the mud made the latter still more

FIG. 6.—Surface map, or top view, of Experiment 21, showing a typical radial tension-fissure pattern caused by a dome-shaped intrusion.

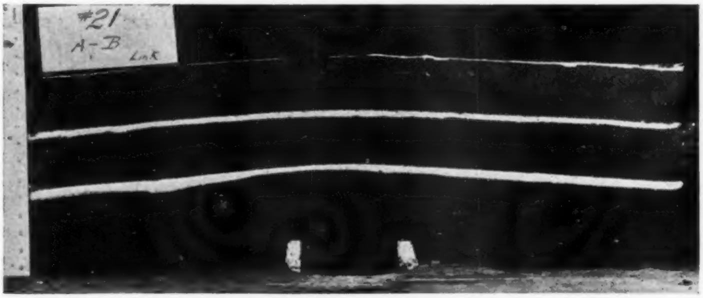


FIG. 7.—Cross section cut through center of Experiment 21, illustrating the effects of a dome-shaped intrusion of semi-rigid mud, the lateral spread of the more fluid mud, and two tension fissures in the upper layers. (Outline of intrusive mass is drawn for clearer definition.)

fluid and caused it to spread out as a sill or sheet beneath the lower plaster layer, as shown in Figure 7.

EXPERIMENT 24 (FIGURES 8, 9, AND 10)

Another attempt to bring in the gas-pressure element was made in Experiment 24. The same arrangement as in Experiment 21 was made, but the mud or clay to be injected was made considerably stiffer by adding more plaster of Paris. Essentially the same artificial strata as those mentioned in Table I were again used in this experiment, *without the overburden of loose sand*. The duration of deformation was about 4 minutes, the maximum uplift measured 11 centimeters, and the resulting area of uplift was about 23 centimeters in diameter.

During the preliminary arrangements a delay occurred, and before the actual application of pressure the mud had begun to set appreciably. In consequence, as soon as pressure was applied by the jack-screw, and aided by the formation of gas from the carbide-water mixture, the upward-moving, essentially rigid cylinder of mud forced its way through the overlying sediments without any spreading whatsoever, and immediately formed a concentric tension fissure at the surface. This break served as the fault plane along which the rigid upward-moving plug actually carried the mass. Eight major radial tension fissures also extended outward from the peripheral break as shown in Figures 8 and 10. Most of the gas escaped along the fault planes already described. The more fluid part of the mud, which was developed by the mixing of the water and gas with the stiffer mud, found its way into branching shear

FIG. 8.—Surface map, or top view, of Experiment 24, illustrating a pronounced concentric break from which eight tension fissures radiate toward the outer peripheral break. The central part of the uplift is closer to the observer than the surrounding part, as seen in the cross section.

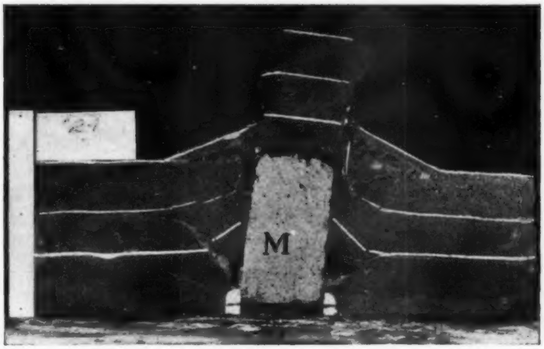


FIG. 9.—Cross section of Experiment 24, illustrating how a relatively rigid intruded mass maintains its shape. Notice the tongues or inclined sills of more fluid material which followed the inclined upthrust fault planes. Courtesy *Imperial Oil Review* (Toronto, April, 1929).

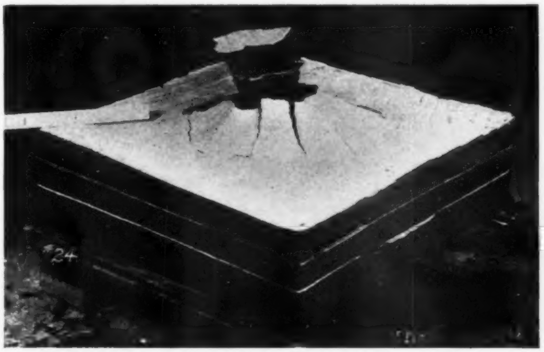


FIG. 10.—Stereogram view of Experiment 24, illustrating a pronounced development of concentric breaks by a flat-topped, relatively rigid, intruded mass. Courtesy *Imperial Oil Review* (Toronto, April, 1929).

planes which were developed during the earlier part of the performance at lower horizons (Fig. 9).

EXPERIMENT 26 (FIGURES 11 AND 12)

The record of the artificial sediments employed in Experiment 26 is given in Table II. A mixture of molten paraffine and petroleum

(grease) with somewhat plastic mud in the upper part of nipple *E* (Fig. 1) was intruded in the usual manner.

TABLE II

RECORD OF SEDIMENTS

Stratum	*Kind of Material*	*Proportions in Kilograms*	*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	None			
Top layer	Thin veneer of plaster	....	....	0.10
Sand No. 2	Sand Cement Plaster Water	7.80 0.80 0.72 3.00	11.32	3.70
Plaster No. 2	Plaster Water	0.42 1.10	1.52	0.20
Clay No. 1	Plastic mud (clay)	2.80	...	...
	Cement	0.40	3.20	2.30
Plaster No. 1	Plaster Water	0.55 1.10	1.65	0.40
Sand No. 1	Sand Cement Water	6.50 0.80 3.00	10.30	3.00
Total			28.04	9.70

Size of opening .... 6.00 centimeters
Duration of intrusion .... 4 minutes (approximately)
Maximum uplift (height) .... 1.30 centimeters
Area of uplift (diameter) .... 20.00 centimeters

Upon application of pressure from below, the characteristic radial tension cracks again formed directly above the hole (Fig. 11), but beyond this nothing happened at the surface because the liquid paraffine had found an outlet along the floor of the box and followed this course.

A low-angle upthrust had already developed in the lower plaster layers (Fig. 12), but this shear plane was not used by the paraffine, for obvious reasons. This experiment serves to illustrate a typical simple radial tension-fissure pattern which develops during the initial stages of intrusions.

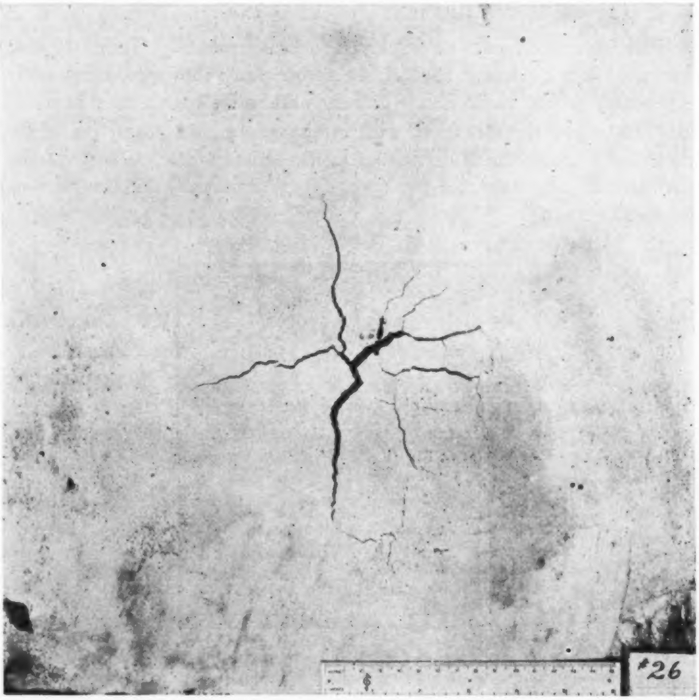


FIG. 11.—Surface map, or top view, of Experiment 26, illustrating a typical radial tension-fissure pattern on a circular dome. From "Origin and Significance of 'Epi-Anticlinal' Faults as Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 858.

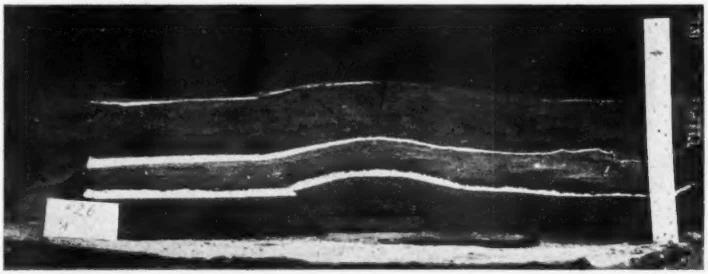


FIG. 12.—Cross section of Experiment 26, illustrating tension fissures in upper strata, and upthrust fault plane in lower white layer.

EXPERIMENT 28 (FIGURES 13 AND 14)

The same sediments as employed in Experiment 26, Table II, were again used in Experiment 28, with the addition of a thin petrolatum layer between the second plaster layer and the underlying plastic mud horizon. The duration of the intrusion, with interruptions, was approximately 8 minutes. The maximum uplift was 4.6 centimeters, the diameter of the structure was 23 centimeters, and the injected material was the same as in Experiment 26.

FIG. 13.—Surface map, or top view, of Experiment 28, illustrating an extreme development of wide radial tension fissures on a dome caused by a dome-topped intrusion of fairly competent material.

FIG. 14.—Cross section of Experiment 28, illustrating relatively low-angle upthrust fault planes and wide tension fissures produced by a dome-topped intrusion of fairly stiff mud and congealing paraffine. Notice the tension fissures in the lower white layer which are independent of those higher. (Outline of the intrusive mud was sketched for clear definition.)

As stated, exactly the same sort of material was injected, but in this case the paraffine had cooled for some time before its intrusion; consequently, it was less fluid and very close to the point of initial solidification. Upon application of pressure the ordinary radial tension cracks developed (Fig. 13). Again, due to a faulty arrangement, the liquid paraffine found its way out along the floor of the box. As soon as this leak was discovered, no more pressure was applied, so as to allow the leak to seal itself by solidification. Finally, when additional pressure was applied, the radial tension fissures grew outward, and opened wide to a considerable depth. The rapid cooling of the paraffine caused it to rise as a dome-shaped mass, and some of the more fluid material found its way upward along the thrust fault planes into the top sand without reaching the surface (Fig. 14). It is very important to observe, when examining Figure 14, that no fluid whatever found its way upward along the tension cracks directly above the intrusive mass, but that all migration was restricted to the shear of thrust fault planes. The very large number of tension cracks developed in the lower plaster layer is striking.

EXPERIMENT 33 (FIGURES 15 AND 16)

In an attempt to study the behavior of a molten mass intruded into homogeneous material, a mixture of molten paraffine and petrolatum was injected into loose, dry, fine-grained sand which was 11.10 centimeters deep and weighed 23 kilograms. The duration of the intrusion was about 8 minutes. The diameter of the opening through which the molten paraffine was injected was decreased from the ordinary 6.25 centimeters to 1.50 centimeters. The resulting uplift was 16 centimeters in diameter.

Upon application of pressure the ordinary dome formed at the surface of the dry sand. Further application caused considerable movement of the sand in the dome, first in one direction and then in another, but finally an extrusion took place along the northeast edge of the uplifted mass. Three distinct flows issued through this first vent, which is well shown in Figure 15. The last two flows extruded through a second vent which developed inwardly from the first. Attempts to break through other planes were manifested by the development of the sudden changes of attitude in the uplifted sand. Upon removal of the sand, the "laccolith" showed a small half-bowl shape, developed upon a more bulbous mass which formed above the hole in the bottom of the box (Fig. 16).

FIG. 15.—Surface map, or top view, of Experiment 33, showing extent of sand affected by an intrusion of molten paraffine which reached the surface and extruded through vents (*V*) and spread out as five miniature lava flows (*L*). The larger vent resembles a crater. Courtesy *Imperial Oil Review* (Toronto, April, 1929).

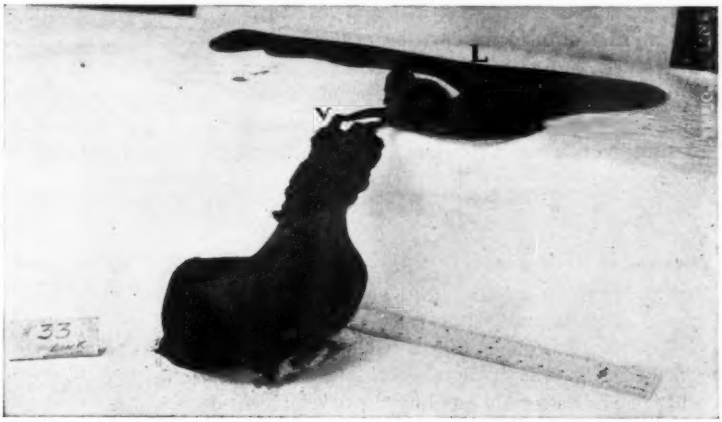
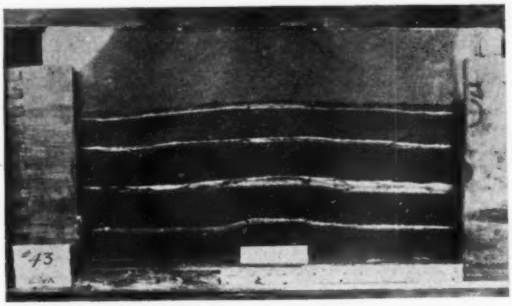
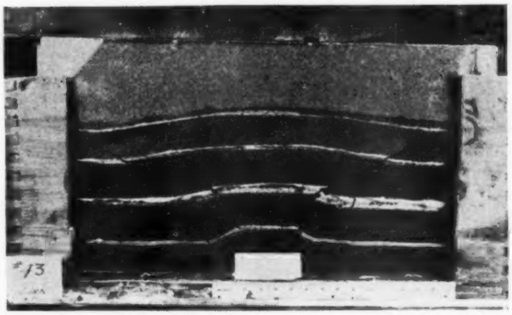


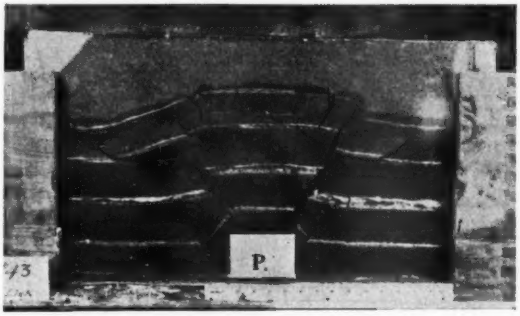
FIG. 16.—Shape of solidified paraffine intrusion (*M*) and its relationship to the vents (*V*) and the surface lava flows (*L*). Courtesy *Imperial Oil Review* (Toronto, April, 1929).



A



B



C

FIG. 17.—Experiment 43, showing successive development of uplift by intrusion of rigid block (*P*) as observed through a plate-glass side of box. *A*, initial stage; *B*, intermediate stage; *C*, final stage. (Photographs are "touched up" to illustrate more clearly the position of the various upthrust fault planes and the surficial tension fissures.)

EXPERIMENTS 42 AND 43 (FIGURES 17 AND 18)

With the object in view of observing in cross section the successive development of fractures produced by the intrusion of a solid block from below into a series of artificial sediments, an apparatus was built with a plate-glass side through which the phenomena could be observed. Experiments 42 and 43 were performed in such an apparatus. The successive development of fractures as observed from their incipient stages to the completion of the experiment is illustrated clearly in Figure 17, *A*, *B*, and *C*, and needs no elaboration.

The asymmetrical development in Experiment 42 was caused by a slight accidental tilting of the push-block (Fig. 18). This caused a normal fault on one side and an upthrust fault on the other. It is significant to notice here the close relationship between the fractures produced by a solid block injected from below and the course of liquid materials when injected in a similar fashion.

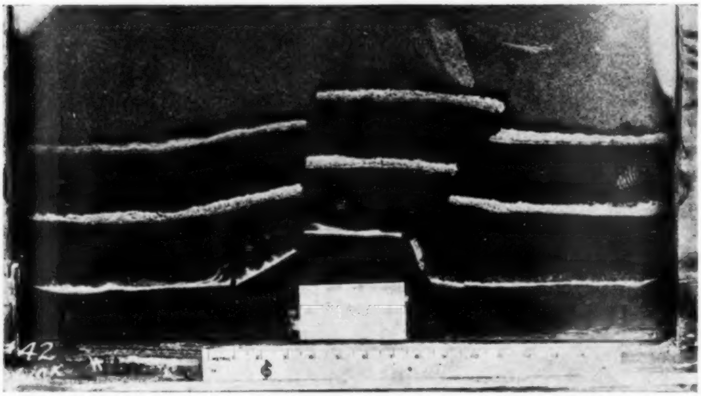


FIG. 18.—Experiment 42, illustrating an uplift with a normal fault on the left and an upthrust fault on the right.

EXPERIMENT 34 (FIGURES 19 AND 20)

In all the experiments previously described the movement of masses upward was accomplished by a force acting vertically toward the surface. No lateral or tangential pressure was applied, so that all movement of the injected masses might be regarded as "positive" or "active," in contrast to that of the artificial sediments, which might be termed "passive." Whether or not conditions in nature may cause such forces

is a moot question, and the results of such experiments must be considered with due regard to these limitations. Before passing on to a summary of the salient features observed in the experiments already described, it seems appropriate to submit one more interesting result.

A series of artificial sediments was prepared and placed in a pressure box which had a length of 55 centimeters, an average width of 36 centimeters, and a depth of 15 centimeters. The side against which lateral pressure was applied was constructed of sheet tin and was caused to bulge outward so that the width at the greatest bulge was 44 centimeters before application of pressure (Fig. 19*A*).

The nature and proportion of "sediments" used in this experiment are given in Table III.

TABLE III

RECORD OF SEDIMENTS

Stratum	*Kind of Material*	*Proportions in Kilograms*	*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	None			
Clay No. 1	Plastic blue mud Cement	8.10 0.98	9.08	3.30
Petrolatum No. 2	Petrolatum	0.70	0.70	0.30
Plaster No. 2	Plaster Water	0.52 0.83	1.35	0.40
Sand No. 2	Sand Plaster Water	10.40 1.57 3.80	15.77	3.00
Plaster No. 1	Plaster Water	0.52 0.83	1.35	0.20
Petrolatum No. 1	Petrolatum (Lens-shaped)	6.00	6.00	2.30 to 3.80*
Sand No. 1	Sand Plaster Water	13.00 2.18 4.00	19.18	4.00 to 2.50†
Total			53.43	13.50

Duration of pressure........................ 9 minutes (approximately)
Maximum uplift........................... 9.50 centimeters

*Represents the petrolatum (grease) in the basin; thickest at center and thinning out laterally.
†Basin in the lowest sand stratum into which the grease layer was placed.

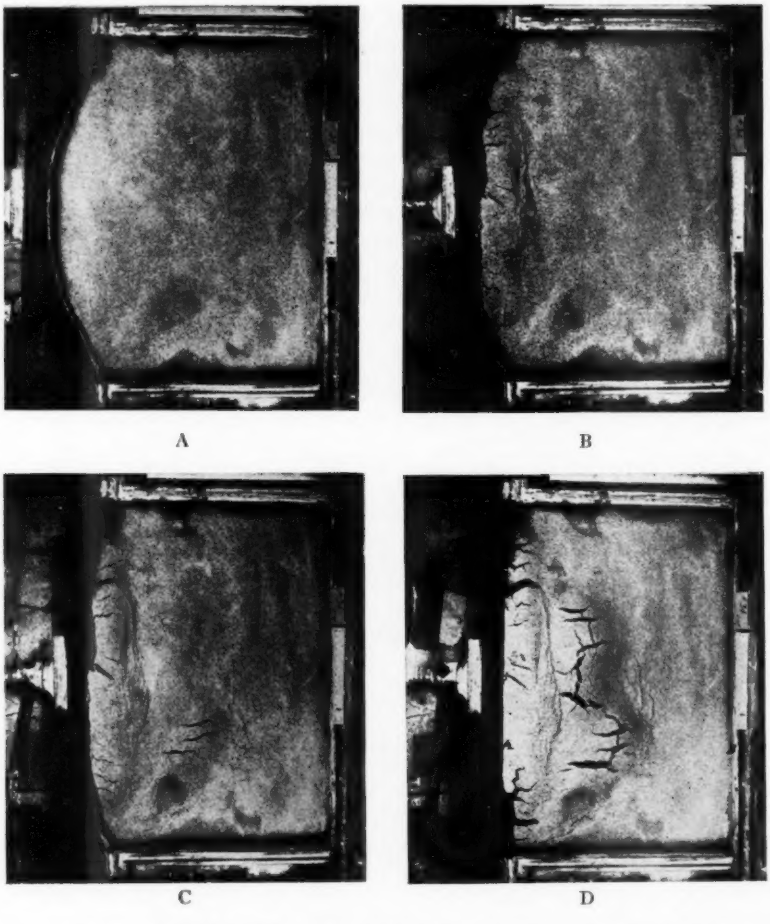


FIG. 19.—Surface map, or top view, of Experiment 34, illustrating the successive surface development of structures produced by applying a maximum compression at the center with a gradual lateral diminution. *A*, surface view *before* application of pressure; *B*, development of a fold close to push-blocks after slight amount of compression (notice transverse tension fissures); *C*, continued growth of first anticline and initial development of ovoid dome farther from source of pressure; *D*, final stage of experiment illustrating three distinct plunging anticlines with pronounced transverse and longitudinal surface tension fissures. (*A-B* is position of section cut through the model.)

The significant feature of the artificial sediments listed in Table III is the basin-shaped layer of soft grease (petrolatum) which was placed above the lowest sand stratum. It was hoped to get some information regarding the behavior of a relatively incompetent, lens-shaped layer between more competent beds when subjected to tangential compression. Similar experiments were performed several years ago by Torrey and Fralich.[1] These investigators found that the plastic, or mobile, layers would thicken upon application of pressure and migrate into the crest, or core of the resulting anticline. The difference between these previous experiments and the experiment described here involves primarily the consideration of the third dimension (width), and the differential application, or lateral diminution, of the applied compressive force. The successive development at the surface is clearly shown in Figure 19, *A*, *B*, *C*, and *D*. The formation of plunging anticlinal folds with surficial transverse tension fissures is apparent. An examination of cross section *A-B*, which was cut through the model (Fig. 20), shows that the lower sand layer was thrust into the thick grease layer or basin, and that the latter showed a tendency to migrate into the core of a fold developed in the overlying plaster of Paris layer close to the side against which the pressure was applied. All cavities above this horizon remained empty.

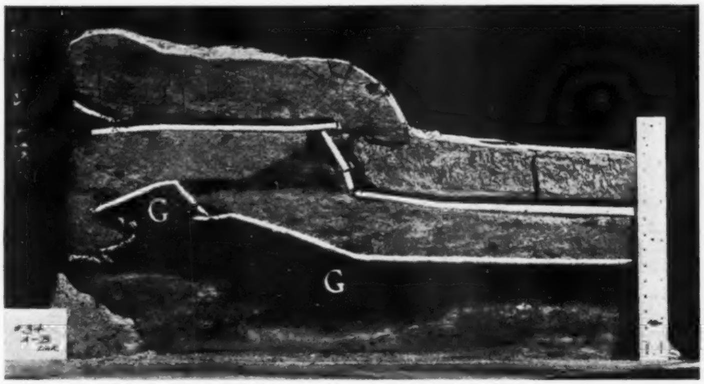


FIG. 20.—Section *A-B* cut through Experiment 34, which shows how the relatively mobile grease layer (*G*) migrated into the core of the lower anticline, and how the lowest rigid sand layer was thrust into the basin of incompetent grease. All cavities above the lower anticlinal structure remained open.

[1] P. D. Torrey and C. E. Fralich, "An Experimental Study of the Origin of Salt Domes," *Jour. Geol.*, Vol. 34, No. 3 (1926).

SALIENT FEATURES OBSERVED IN THE EXPERIMENTS

The following are the most outstanding features observed during the performance of the experiments described in this paper.

1. The invariable development of *surficial tension fissures* on structures produced by the injection of rigid or incompetent material from below.

2. The development of a *tension-fissure* pattern in *lower-lying* brittle layers independent of those at the surface.

3. The development of *surficial tension fissures* on structures produced by tangential compression.

4. Manifestation of *incipient* tension fissures by minute *en echelon* breaks.

5. The preponderance of *radial* tension fissures on domes produced by the intrusion of arched or dome-topped cylinders.

6. The preponderance of *concentric* or peripheral tension fissures on domes produced by the intrusion of flat-topped cylinders.

7. The *lateral*—in some cases horizontal—spread of intrusions composed of incompetent, or non-rigid material.

8. The development of *inclined* upthrust fault planes with the intrusion of rigid or mobile masses.

9. The conspicuous *bowl-in-bowl* development caused by a series of such upthrusts.

10. The movement of incompetent or mobile material toward the crests of structures produced by tangential compression.

11. The shape of such intruded bodies as are not capable of assimilating or melting the surrounding country rock and the resulting structures are dependent upon the following factors: (a) viscosity of the injected material; (b) nature of the sediments, that is, their competency, plasticity, brittleness, et cetera; (c) structure of the sediments before the intrusion; and (d) rate of intrusion (time factor).

CONCLUSIONS

The features here cited are probably not all-inclusive. Some readers may possibly notice others and regard some of these as of minor importance. It seems to the writer, however, that an upward moving mass, propelled by a force from below and unaided by tangential compression, can not maintain its shape unless it is endowed with a rigidity greater than that of the surrounding country rock. It is true, however, that an incompetent or otherwise mobile mass moves upward and nearly maintains its shape when it is aided by tangential compressive forces. If

such forces are from the east or west, or both, the incompetent mass rises, but must also spread laterally north and south, thus assuming an elongated shape at right angles to the compressive forces.

Whether or not the surficial tension fissures could give rise to detectable structural features is problematical. On a rising dome, where erosion would be more active, it is possible that stream adjustment in harmony with the tension-fissure pattern could take place without any detectable structural displacements along such fissures.

DISCUSSION

W. ARMSTRONG PRICE, Houston, Texas: Three different attempts have recently been made to reproduce, through mechanical models, by intrusive methods, the structure and dynamics of salt domes. These experiments were, in part at least, stimulated by the symposium on salt domes held by the American Association of Petroleum Geologists at its meeting in Houston in 1924. W. T. Thom, Jr., and Max W. Ball have been credited by the authors of the first of these studies[1] with having made the suggestion at the Houston meeting that such experiments would be helpful to salt-dome students.

The interesting and valuable work of Link, presented at the current meeting of the Association, was preceded, but not forestalled, by that of Torrey and Fralich. These writers used a stratified series of beds containing a thick, plastic mass between more rigid layers. The whole was strongly folded by tangential compression, resulting in the uplift of an anticline, accompanied by overthrust faulting, surficial tension fissures, and the rise of the plastic mass in a plug-like body into the axis of the anticline and up the fault planes. The compression was applied from one side or from opposite sides and was evidently varied during the production of any one model. Under the maximum pressure the plug of mobile material separated from the bed from which it had come. Small knobs formed on the upper surface of one of the plugs. Because of the brittleness of one of the beds involved, and the extreme compression employed, parts of the crest of the anticline broke up into blocks, which the authors likened to similar structure described by van der Gracht[2] from European salt domes.

The axial length of the anticline permitted by the enclosing sides of the box was short. The diameter of the lens of mobile material was also relatively short. The mobile mass, therefore, simulated a small lens of salt, not a bed of wide distribution.

In another series of experiments by the same writers, stiff grease was forced upward through a small orifice (1/16 inch) into layers of loose sand. Doming resulted, with a surficial mound, cut by radial tension fissures and normal faults. The top of the grease intrusive was illustrated by a contour map which is typical of the rather flat-topped domes of the Gulf Coast, as commonly contoured

[1]Paul D. Torrey and Charles E. Fralich, "An Experimental Study of the Origin of Salt Domes," *Jour. Geol.*, Vol. 34 (1926), pp. 224-334, Figs. 1-10.

[2]W. A. J. M. van Waterschoot van der Gracht, "The Saline Domes of Northwestern Europe," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), pp. 85-92.

by the geologists who have studied them. In one experiment, the intrusion penetrated a layer of white sand and carried a horst block of this bed upward into the overlying stratum.

These experiments were neither so extensive nor so clearly illustrated as those of Link.

The elaborately illustrated and carefully controlled series of experiments by Escher and Kuenen[1] has recently been reviewed for the Association by Barton.[2] They studied the behavior of a stratified series, under vertically active forces, both with uniformly plastic strata and with beds of alternating plasticity, as the whole rose into a confining cylinder and formed vertical-sided, cylindrical up-folds of the diapir type which produce the piercement salt domes. In some experiments, the vertical forces were opposed by others of less strength. In these experiments, only the actions within the "mother" beds of salt and within the intruding salt core of a salt dome of this type were studied. In the experiments of Torrey and Fralich, as well as in those of Link, the action within the intruding body was not investigated, but only its outward form and its effect upon the intruded strata.

Link's investigations included one of the type performed by Torrey and Fralich. In this experiment, room was given in the model for the complete growth of an entire group of anticlines which were transverse to the compressive force, plunging at each end, arranged *en échelon*, and varying by 45° in axial direction. The mobile body rose into the axis of one anticline in a manner simulating a salt anticline, not a plug. An upper anticline died out in depth, being represented by a terrace on the flank of a larger anticline below. Both in Link's experiments and in those of Torrey and Fralich, asymmetrical anticlines only were investigated. In both groups of experiments, the tangential forces were greater in one direction than in the opposite direction.

The results of the Link experiments in which no tangential pressure was involved are the most important for comparison with those parts of the Texas and Louisiana salt domes which have, as yet, been explored with the drill. It may be that the Boggy Creek salt dome of the interior basin of East Texas will prove to be of the salt anticline type. The geologists of the Humble Company will doubtless, in due time, give us a study of this interesting structure. At present we have no published description of a typical salt anticline in Texas or Louisiana. The deep domes recently found on the Gulf Coast, and now being actively explored by the drill and by geophysical methods, may yield salt anticlines and structures as yet unknown in this area. Further exploration on the interior domes will take us nearer to the bases of these structures and may yet reveal in some deep hole the "mother beds" of the salt and the roots of domes.

Link's clear and comprehensive summary of the general structural and dynamic results of his work leaves little to be added, except to draw comparisons with known salt dome types.

The main conclusion drawn by Link, that

[1] B. G. Escher and P. H. Kuenen, "Experiments in Connection with Salt Domes," *Leidsche geologische Mededeelingen*, Deel 3 (1929), Aflevering 3, II, pp. 151-82, Pls. 20-38.

[2] Donald C. Barton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 107-08.

> an upward-moving mass, propelled by a force from below and unaided by tangential compression, can not maintain its shape unless it is endowed with a rigidity greater than that of the surrounding country rock,

seems well evidenced by the experiments. His conclusion that

> an incompetent or otherwise mobile mass moves upward and nearly maintains its shape when it is aided by tangential compressive forces

seems to the reviewer to be true only over a very limited range of conditions, in view of the work of Torrey and Fralich.

There would seem to be some ground for extending these conclusions so as to make them apply to intruding bodies of approximately the same rigidity as that of the country rock. In Link's experiments, such intruding bodies not under tangential forces seem to rise through the sedimentary series with their shape not greatly changed where the uplift proceeds rapidly and for relatively short vertical distances.

The prismatic horst blocks which are striking features of the Link models may, from one standpoint, be considered as parts of the intruding masses, and would fall in such a class of intrusives as have approximately the same rigidity as that of the country rock. The rise of the horsts is similar to that of intrusive bodies, in that both compress, fault, and pass through the immediately overlying beds. Further upward movement is then aided by the faults so formed. Geologists writing in *Geology of Salt Dome Oil Fields*, one of the Association's symposium volumes, have, with one exception, not illustrated or seemed to recognize horst blocks. Spooner[1] shows a horst bounded by normal faults above the Vacherie dome. He shows one reverse and three normal faults on this dome. There is a possibility that horsts are more common than has been supposed on the Gulf Coast domes, especially on those with the more flat-topped cores. It may be that, on a structure such as that of Saratoga,[2] the Oligocene above the cap is in a horst and not folded up in a continuous, thin veneer over the cap, as it has been illustrated in cross section.

The term "upthrust," instead of *reverse*, used to describe the fault-plane shown farthest at the right in Figure 18 and elsewhere in Link's paper, does not seem the best usage. Both faults shown in the illustration are "upthrust" as to the actual motion involved. The fault at the left in this illustration, described as "normal," has a curving, but practically vertical, fracture surface. It is doubtfully normal in form, and is the only example of a fault approaching normal faulting shown by the models.

Link's experiments are helpful in picturing what possibly results from salt-dome growth under simple conditions. Actual conditions may, as Link suggests, produce more complex forces and structures. Those models which were formed without tangential forces show marked similarity to Gulf Coast salt domes of Louisiana and Texas. In making this comparison, it must be remembered that the models can be more thoroughly explored than the salt domes. Of necessity, much generalization and interpolation must be injected into all illustrations of actual subsurface conditions on buried salt domes.

[1] W. C. Spooner, "Interior Salt Domes of Louisiana," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 297.

[2] *Op. cit.*, p. 509.

Our knowledge is being advanced, both in degree and in amount, by improvements in subsurface exploratory methods and equipment. There is also the usual caution to be observed in the interpretation of models. The difficulties of adjusting scale, materials, and time, as well as forces, to reproduce actual conditions which exist at unexplored depths make us duly cautious in pressing similarities and differences.

With the reservations suggested, we may attempt to draw at least some general parallels between Link's models and Gulf Coast salt domes.

In the Link experiments, the intrusive bodies and their companion horsts picture the salt cores with cap-rock riders, whether the latter are fragments of deep-seated strata or are residual from salt solution. Riders of other less competent types may be discovered on deep domes.

Super-cap sediments are domed and slightly compressed.

Steep flank dips are formed.

Some domes are asymmetrical.

Structural features are, in general, more pronounced in depth.

Thrust faults and horsts originate in depth.

Marginal fault wedges suggest why the flanks of some domes present areas of irregular sands and irregular producing conditions.

The intrusion of more mobile beds along the thrust-fault planes suggests possible flowage of loose sands and shales on the salt domes upward into these marginal zones.

Lateral thickening of beds in some of the fault wedges, and thinning of others against the intrusive body, also suggest some of the irregularities of subsurface formations on the Gulf Coast domes.

Other features shown by the models are not so well or so fully known on the Louisiana and Texas domes. Faults on buried salt domes are not, in general, well known in detail. It can hardly yet be said that the typical fault pattern of Gulf Coast domes is known, or that there is a typical pattern. In the models, faults are reverse; they hade toward the salt; those formed first are ordinarily of lower hade than later faults; faults originate in depth and travel upward with the progress of intrusion; fault planes may be convex toward the salt.

Radial faults, suspected on some Gulf Coast domes, and transverse faults, such as one which has been illustrated on one of the interior domes of Louisiana, are not shown in the models where lateral compression is absent. May it be possible that successive periods of growth, perhaps with some oscillation in the vertical, can develop radial normal faults from the radial tension fissures? These faults might remain of relatively short vertical extent, or might become deep with the progress of uplift. Radial faulting was shown in the Torrey and Fralich models under strong tangential compression.

Radial and transverse tension fissures may be the cause of some central basin-shaped or transverse topographic depressions above buried salt domes. Transverse depressions across the Blue Ridge and Big Hill (Jefferson County) salt domes, described by Barton in a forthcoming paper[1] as probably having

[1] D. C. Barton, "The Deltaic Coastal Plain of Southeast Texas," *Bull. Geol. Soc. Amer.*, in press.

originally been stream courses, may have originated in the manner suggested by Link, who says:

> On a rising dome, where erosion would be more active, it is possible that stream adjustment in harmony with the tension-fissure pattern could take place without any detectable structural displacements along such fissures.

There seem to be three chief contributions of the three sets of experiments to the theory of salt-dome structure and dynamics.

1. They actually produce, under controlled dynamic conditions, models which closely reproduce many characteristic salt-dome structures.
2. They show, diagrammatically, structural features which are known or believed to occur on salt domes, but which can not be satisfactorily proved on the buried domes until after much additional drilling has been done.
3. They show the characteristic and common occurrence of tension fissures in both compressed and uncompressed structures.

These experiments, with their clear and full presentation, should stimulate other investigators to test further the conclusions suggested by the results of Link's work and that of others, and to cover the range of all classes of salt domes with enough experiments in each class to permit more thorough sifting of results by the statistical method.

Barton, in his review of the Escher and Kuenen experiments, points out some of the indicated lines of additional research.

1. The further prosecution of the vertical-pressure-and-disc-apparatus experiments to investigate non-diapiric domes, faintly diapiric domes, and salt-dome ridges.
2. A search for clues as to the difference between domes formed under isostatic and tangential thrust.
3. A quantitative mathematical investigation of the competence of the possible isostatic thrust to account for the upthrust of the salt.

To these may be added the following.

4. An elaboration of the tangential pressure experiments, with greater ranges in the variables (*competency* and *rigidity* of the strata), and with wider variations in the strength of forces, size of area, and thickness of vertical section.
5. A study of oscillatory uplift in salt domes. Possibly the marginal synclines on interior Texas domes[1] can be explained by oscillation of the intruding body, rather than by subsidence due to withdrawal of salt around the base of the dome as it rose into the core.
6. The production of super-cap and flank normal faulting.
7. Quantitative data on the strength, brittleness, rigidity, mobility, and plasticity of the artificial sediments used.
8. Statistical studies of the results of experimentation, after a large number of models of the various types shall have been produced under well controlled conditions.

Supplementary note.—A feature worthy of comment in connection with Link's experiments was brought out in the presentation of papers at the New Orleans meeting of the Association.

[1]E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas, with Special Reference to Mount Sylvan Salt Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (1929), pp. 1347-75.

An illustration of an experiment performed by Link, but not described in the *Bulletin*, showed a migration of the axis, or locus, of doming above the intrusive body. This migration resulted in a buried domal structure at one side, above the intrusive, and, later, a separate dome at the other side. The first dome did not ascend as high as the upper part of the second dome. Some irregularities in salt dome mounds may be connected with such migration of the locus of doming. The migration itself, if I rightly understood Mr. Link, was caused during a relatively slow intrusion, or perhaps during one periodically repeated.

Irregularities in the form of the salt of some domes may be due to a shifting of the axis of intrusion during a long period of upward motion.

MAGNETOMETER SURVEY OF LITTLE FRY PAN AREA, UVALDE AND KINNEY COUNTIES, TEXAS[1]

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Fort Worth, Texas

ABSTRACT

Magnetometer investigations of igneous intrusions along the western end of the Balcones fault zone in the southwestern part of Texas show that the intrusions are highly magnetic. Some plugs are positive and others negative; in several, splinters of the igneous rock were found to be polarized. The results of the work in this area indicate that magnetic instruments can be used with success to determine the presence or absence of buried igneous intrusions.

Little Fry Pan is a prominent topographic and structural feature extending from the southwestern part of Uvalde County into the southeastern part of Kinney County (Fig. 1). The name, which refers to a skillet-shaped basin near the center of the disturbance, has been applied by geologists to the entire anticline. The general area is near the head of the Rio Grande embayment, not more than 40 miles east from the locality at which the Balcones fault system crosses Rio Grande into Mexico. It is an interesting geological province, for it exhibits not merely the effect of the faulting of the Balcones with its associated basic intrusions, ash deposits, and peculiar doming of surficial beds, but, in the surface trace of formation contacts, a distinct reflection of the tectonics of the embayment.

The general trend of the Little Fry Pan anticline is northeast-southwest, and along this axis are four distinct domes located approximately 1 mile apart. The uplift can be followed for slightly more than 5 miles along the major axis; its average width is about 1½ miles. The maximum amount of surface uplift within the area outlined occurs on the central and largest dome and is approximately 250 feet; the lower domes at the ends of the disturbed area have 100 feet less uplift. Probably the most striking feature of the Little Fry Pan anticline is the Anacacho limestone which blankets the entire uplift. A single bed of this asphalt-bearing, organic, fragmental limestone of Upper Cretaceous age forms the surface

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, February 5, 1930.

[2]The Pure Oil Company.

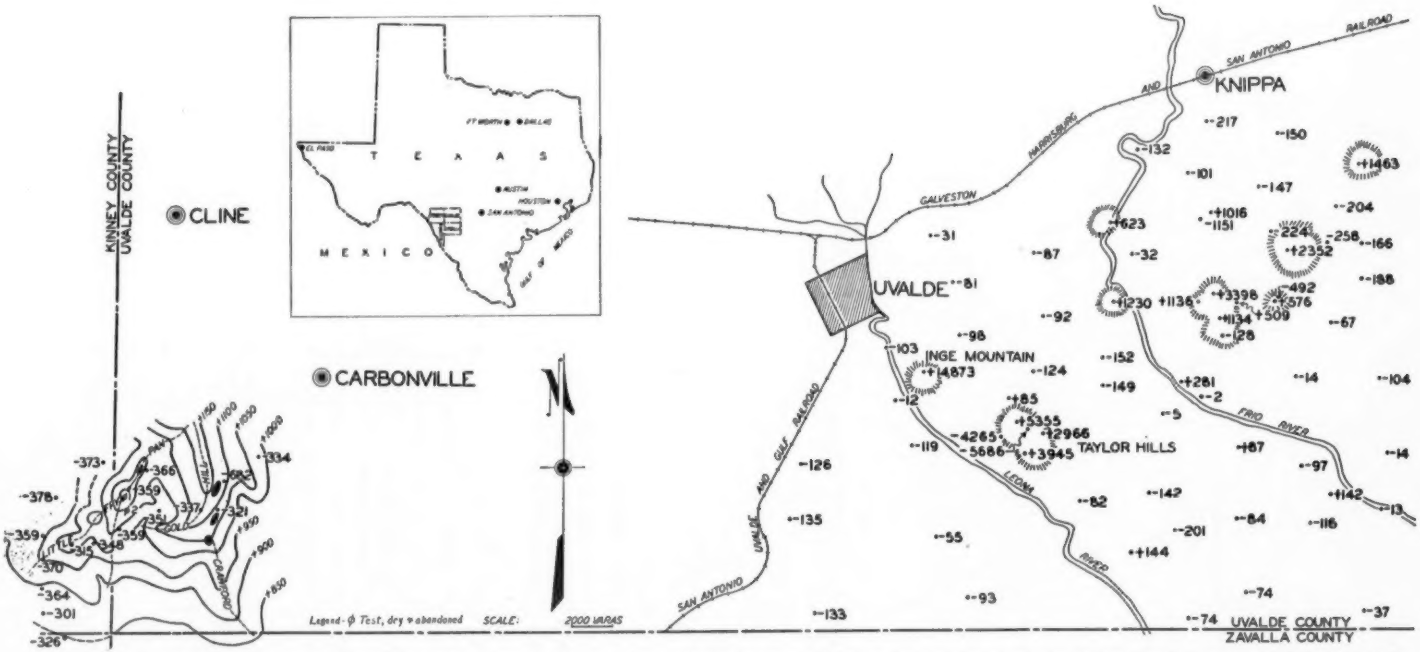

FIG. 1.—Magnetometer survey of the south part of Uvalde County, Texas, including generalized surface structure of the Little Fry Pan area. Only a few of the observed stations are recorded on this map. Magnetometer readings are in gammas; structural contours are in feet. Scale: ¼ inch = 2,000 varas, or 5,555.5 feet.

rock of nearly the whole anticline. Except for a little grass and here and there a stunted tree, the top and a large part of the flanks are of barren limestone with little or no soil. The mapping of surface structure presents no difficulties and there is almost unanimity among those who have surveyed the area.

Little Fry Pan is not entirely a unique type of surface uplift for this region—east of it is the Gold Hill anticline, and southeast is the Crawford anticline—but it is distinctive in that it is the most regular of the structures in the area, lies farthest southwest, and is located at the greatest distance from the igneous activity which characterizes the western part of the Balcones fault zone in Texas. The Crawford anticline and the Gold Hill anticline are intruded by several bodies of basic igneous rock, some of which are several acres in extent, but thus far no evidence of igneous activity has been seen at the surface of the Little Fry Pan anticline, though the structure has been examined with considerable thoroughness.

Extreme local saturation of the Anacacho limestone with heavy asphaltic oil, principally in the western part of Medina County and in Uvalde County, where this old beach deposit reaches its maximum development, has led to the testing of this formation where it is sufficiently buried. Commercial deposits of road metal have been found in localities in which the limestone has the proper saturation with asphalt, but little encouragement has resulted from drilling for oil.

Following the discovery of large oil fields in the Edwards limestone, of Lower Cretaceous age, on faults which are a part of the Balcones system in Guadalupe and Caldwell counties, showings in the same formation farther west in Bexar and Medina counties, and small production in the Glenrose formation below the Edwards in Maverick County, attention was directed to the prominent surface structures of Uvalde County. They were recognized to be a type of structure entirely different from the producing faults of the Balcones system, but, as they were underlain by the formations which were producing in the same geological province, it was believed that they were worth consideration. Opinion seemed to be nearly unanimous that the prominent surface disturbances, the Little Fry Pan, Gold Hill, and Crawford anticlines, were underlain, probably at shallow depth, by igneous rocks. As in places on both the Gold Hill anticline and the Crawford anticline basic intrusions actually had penetrated to the surface, it was thought that the parent body from which the dikes and necks came underlay the structures and was their chief cause. Little Fry Pan was considered to be of the same composition as the two

adjacent structures, and the absence of igneous material at the surface was credited to accident.

With the perfection of the magnetometer, attempts were made to locate buried serpentine masses similar to those at Thrall, Lytton Springs, and Dale, where commercial production had been found in altered basic rocks, particularly in the horizons of the Austin and Taylor formations of Upper Cretaceous age. If the serpentine masses were ordinarily basaltic and probably magnetic, weathering, which altered them to serpentine, had oxidized the iron so that it was no longer sufficiently magnetic to be distinguished from slight irregularities and variations in magnetic readings entirely independent of rock content. This led to the study of exposed igneous masses, both serpentine and basalt. It was felt that if a basalt plug lay deep enough below oil-bearing beds which it had uplifted into favorable structure so that no alteration had been induced in the oil horizon, there were possibilities for production.

A study of the exposed igneous plugs[1] in the southern part of Uvalde County where they are the most numerous and accessible shows a wide variation in their magnetic properties. The magnetic intensity for the southern part of Uvalde County where not influenced by igneous rock ranges from −200 to +100 gammas.

Inge Mountain, 2 miles southeast of the town of Uvalde, is classified as Uvalde phonolite.[2] Of the several readings taken on its summit the highest was +14,873 gammas. It was found that the maximum or the minimum intensities on these plugs occur over the vents through which the intrusive magma ascended. Toward the edges of mushroom-shaped plugs, or on flows, even as thick as 100 feet, the influence of the igneous rock is negligible in comparison with intensity measured over vents. This suggests that mass is an important factor. It may be mentioned that these magnetic studies revealed that some vents are located considerably aside from the center of plugs.

The Taylor Hills, which are also on the east side of Leona River 3 miles southeast of Inge Mountain, are classified by Vaughan[3] as nepheline-melilite-basalt. Although their composition may be homogeneous, there

[1]Most of the outcropping igneous rocks along the western part of the Balcones fault zone in Texas are basalt or phonolite. For a classification of the important exposures see T. Wayland Vaughan's "Uvalde Quadrangle, Texas," *U. S. Geol. Survey Geologic Atlas of the United States* (Washington, D. C.). The petrographic descriptions are by Whitman Cross.

[2]*Ibid.*, p. 4.

[3]T. Wayland Vaughan, "Uvalde Quadrangle, Texas," *U. S. Geol. Survey Geologic Atlas of the United States* (Washington, D. C.)

is a wide range in their magnetic content. The minimum reading of this locality was −5,686 gammas, and the maximum, +5,333 gammas. It was also discovered that in the Taylor Hills, and in fact in most other intrusions, there is a decided polarization in the masses. Not only are particular parts of the mass positive, whereas other parts are negative, but splinters of basalt 6 inches long were found to have positive and negative ends.

On the west bank of Frio River, due east from Uvalde, there are two small phonolite hills. The northern hill gave a maximum positive reading of 623 gammas, and the southern, a maximum of +1,230 gammas.

East of Frio River, 3 miles east of the aforementioned plugs, is a large hill composed of nepheline-melilite-basalt. At its northern end a reading of +3,398 gammas was secured; at its western edge, of +1,136 gammas; near its southern limit, of +1,134 gammas.

One-half mile east of this outcrop, readings in a limited area vary from −492 gammas to +576 gammas, and although no igneous rock was observed, it is thought to be present, but not in a large mass.

Three and one-half miles south of Knippa, there is an area where a plug is suspected, although it is not exposed. Readings within a distance of a few hundred yards range from −1,151 gammas to +1,016 gammas.

Four and one-half miles southeast of Knippa and just west of Long Hollow is a knob of nepheline-melilite-basalt with a maximum value of +2,352 gammas and a minimum of −258 gammas. Two miles farther northeast, 3 miles southeast of Knippa, is a small plug of similar composition which showed a value of +1,463 gammas.

The study of some of the exposed igneous rocks in the southern part of Uvalde County indicates that individual basalt or phonolite knobs may be magnetically positive, or they may be negative, or there may be positive and negative areas in the same outcrop. Furthermore, it was learned that splinters of basalt or phonolite may be polarized sufficiently so that in a small fragment there is enough intensity to attract or to repel a compass needle.

One of the most important facts indicated by the survey of exposed igneous rocks of Uvalde County is that the masses are so active magnetically that they can be located by magnetometer surveys. It was also suggested that the flanks, at least of the exposed masses, are nearly vertical, that is, the subsurface areas of the plugs are not much greater than the exposed areas. Buried igneous masses, if large enough, are readily detected.

With this information by which to interpret data, a magnetometer survey of the Little Fry Pan anticline was made to ascertain if it was

underlain by basalt or phonolite, or if there was any relation between the surface structure and buried igneous masses. It was determined that the normal magnetism of the territory surrounding the Little Fry Pan anticline ranged from −300 to −400 gammas; on the structure itself not the slightest suggestion of buried igneous rock was found. Consequently a well, Smyth and Smith No. 1, was located on the center and highest dome on the Little Fry Pan anticline. It was planned to make a test of the Edwards limestone, in or below which there was a good showing of oil in Graves No. 1, located in Zavalla County, 8 miles east of south from Little Fry Pan.

The following summarized log[1] shows the nature of the material penetrated in Smyth and Smith No. 1 drilled in 1927-28 by The Pure Oil Company.

LOG OF SMYTH AND SMITH NO. 1, LITTLE FRY PAN ANTICLINE

Elevation above sea, 1,164 feet

Depth in Feet	*Formation*
0- 85	Anacacho limestone, compact, but with several porous zones, many fossil fragments, and asphalt in many places
85- 230	Limestone with much serpentine or chloritic material, some asphalt, and rounded sand grains
230-1,000	Limestone and shale with volcanic ash and serpentine
1,000-1,145	So-called serpentine
1,145-1,550	Sediments with volcanics, much chalk and limestone
1,550-1,586	Eagle Ford shale. Top may extend upward into volcanics
1,586-1,718	Buda limestone
1,718-1,845	Del Rio marl
1,845-2,340	Limestone. At 2,100 feet, a hole full of sulphur water
2,340-2,550	Some anhydrite and sand and shale with the limestone. Cavity from 2,480 to 2,500 feet. Between 2,470 and 2,480 feet a hole full of water
2,550-3,135	Limestone, in part at least upper Glen Rose. Top, plentiful *Orbitolina texana* zone at 3,135 feet
3,135-4,810	Increasing shale and sand
4,810	Total depth. Hole full of fresh water

In Smyth and Smith No. 2, which is located 2,000 feet east of south from Smyth and Smith No. 1 and 70 feet lower on surface structure, the lithology of the section above the Buda limestone is very different from that found in No. 1. Both wells begin in the Anacacho limestone, which is similar in character, but Smyth and Smith No. 2 reaches the Austin at least as high as 755 feet. It is a white, finely crystalline limestone,

[1]Abstracted from a detailed log by N. L. Thomas and M. F. Bohart of The Pure Oil Company.

whereas at the corresponding depth in Smyth and Smith No. 1 the material is volcanic; furthermore, in Smyth and Smith No. 2 the material from a depth of 700 feet to the base of the Austin is fairly pure limestone; in Smyth and Smith No. 1 volcanic matter is predominant throughout the Austin section. In neither well, however, is evidence of igneous material found below the Buda limestone, and in this there are only a few chlorite specks. Below the Eagle Ford the beds in both wells are fairly regular.

No original igneous rock was encountered in drilling the Little Fry Pan anticline, and it is believed that no such mass exists under it. The reason for the presence of the surface structure is not known; perhaps it is due in some way to the concentration of an abnormal amount of light volcanic material, as shown in Smyth and Smith No. 1 and the considerably smaller amount in Smyth and Smith No. 2.

It is also interesting to note the change of lithologic character in the Glen Rose between Little Fry Pan and the Chittim area in Maverick County. In the Chittim area the Glen Rose is composed chiefly of dark gray and black bituminous limestone and shale, whereas at Little Fry Pan there is almost a total absence of bituminous matter, the limestone being gray and tan, and the shale light in color.

In Uvalde County it is considered that the drilling of the Little Fry Pan anticline has proved that magnetic instruments can be used with success in certain areas where specific problems are to be solved.

DISCUSSION

D. M. Collingwood, Dallas, Texas: Mr. R. A. Liddle's paper demonstrates a successful use of the magnetometer for the discovery of buried basaltic igneous necks. A similar use of the magnetometer has been found of direct economic value in exploration for oil in other places along the Balcones fault system.

There is often misunderstanding on the part of oil company executives and others engaged in the oil exploration business regarding the data furnished by geophysical maps, because many of them do not have as a background even an elementary understanding of the physical quantities measured by geophysical instruments. For this reason it seems all the more important that we should be consistent and accurate in reporting the results of a magnetometer survey. To those conversant with magnetics it is of course plain that when Mr. Liddle uses the expression "magnetic intensity" in referring to the data shown on the map, he means magnetic intensity anomaly as compared with some location where the intensity is arbitrarily regarded as zero, or of normal intensity for the particular area. To others it may be misleading, especially in comparing reports on adjacent areas, and the writer would suggest that the word anomaly should be used, where proper, to differentiate from absolute intensity data.

It is also the experience of the present writer that magnetic anomalies are found over buried igneous necks, although the buried, laterally disposed, mushroom tops or flow bodies of serpentine, altered from such basaltic rocks, do not in many places give appreciable anomalies. Furthermore, this is true in spite of the fact that hand specimens of the so-called serpentine or altered basaltic rock, taken from core samples, have shown magnetic properties.

Regarding large anomalies over necks, Mr. Liddle suggests that mass may be a factor. As a modification and amplification of this, the writer suggests that the peak anomaly over a plug is a function of its magnetic permeability, its parallelism with the earth's magnetic field, its continuity in the direction of the earth's field, and its cross-sectional area.

The opposite polarities found in some of these igneous bodies are particularly striking. Probably all interested in magnetometer work would welcome further discussion on this phenomenon and would like to have Mr. Liddle's opinion regarding an explanation of the presence of the pronounced negative anomalies in this area.

R. A. Liddle: Mr. Collingwood's suggestion about referring to the measured magnetic forces as magnetic intensity anomaly instead of magnetic intensity, meets with no objection from the writer if by the inclusion of the word anomaly a clearer picture will be presented to non-technical men; however, the writer wonders if many oil company executives know that an "anomaly" is the difference between the terrestrial and the true magnetic magnitude. In this particular magnetic survey the writer had in mind the contrast between the magnetic intensities on the igneous plugs and the normal magnetic intensity of the surrounding territory.

Polarization in igneous intrusions, he believes, is a normal condition; it is as logical as the crystal arrangement and mineral segregation which take place during solidification of magma.

Negative magnetic values he considers to be as regular as positive values. So far as he is aware, negative magnetic values are no more exceptional or abnormal than positive magnetic values. In the Little Fry Pan area the negative readings are no more pronounced than the positive readings.

GEOLOGICAL NOTES

LIGNITE IN DOLOMITE

Lignite was noticed in dolomite cores from several diamond drill holes in south-central Tom Green County, Texas. Ordinarily the presence of lignite in cores from certain formations is common enough, but lignite in a dolomite from the Clear Fork member of the Permian seems worth noting.

Following is a partial log of a test well on the McKinzie land about 1½ miles west of Christoval.

Depth in Feet	*Description of Formation*
400-409	gray dolomitic lime
409-412	greenish gray shale
412-414	light gray dolomite
414-425	gray porous dolomitic lime
425-430	green shale
430-433	light gray lime
433-435	dark gray calcareous lignitic shale
435-437	light gray spangled lime
437-441	lignitic calcareous shale and dolomite
441-458	gray and buff dolomite with lignite
458-461	gray shale and lime
461-474	dark gray calcareous shale
474-477	porous gray lime
477-486	gray shale
486-491	porous gray lime, little lignite
491-494	dark gray calcareous shale
494-496	gray dolomitic lime

From this log, which is typical of the area, it is seen that the Clear Fork in south-central Tom Green County consists of an alternating series of limestones and dolomites interbedded with calcareous and lignitic shales. In order to be assured that this was a true dolomite, an analysis was made of a sample from a depth of 452 feet in the McKinzie test hole.

Following is an analysis of this sample compared with a dolomite described in Clarke's "Data of Geochemistry."

Dolomite—Clarke		*Sample 452 Feet—McKinzie D-10*	
SiO_2	3.24	SiO_2	2.4
Al_2O_3	.17	Al_2O_3	.68
Fe_2O_3	.17	Fe_2O_3	.70
CaO	29.58	CaO	30.71

MgO	20.84	*MgO*	19.46
CO_2	45.54	CO_2	45.37
FeO	.06		
H_2O	.30		
	99.90		99.32

The sample from 452 feet is a fine-grained, dense, buff dolomite. Under the microscope this sample is seen to be made up of minute dolomite crystals and is somewhat porous, which condition is generally characteristic of dolomites. Some of the cores have a mottled appearance, due to the occurrence of patches of gray lime, lignite, and large calcite crystals in the midst of the buff dolomite. The fragments of lignite, which range in size from minute specks to particles with a diameter of 1 inch or more, are in many places completely surrounded by pyrite and impregnated with small veins of calcite (Figs. 1-3).[1] A good-sized piece of dolomite was placed in hydrochloric acid and in a comparatively short time only a few grains of quartz remained.

It might be interesting to speculate on the probable origin of these particular limestones and dolomites. Evidently they were deposited in

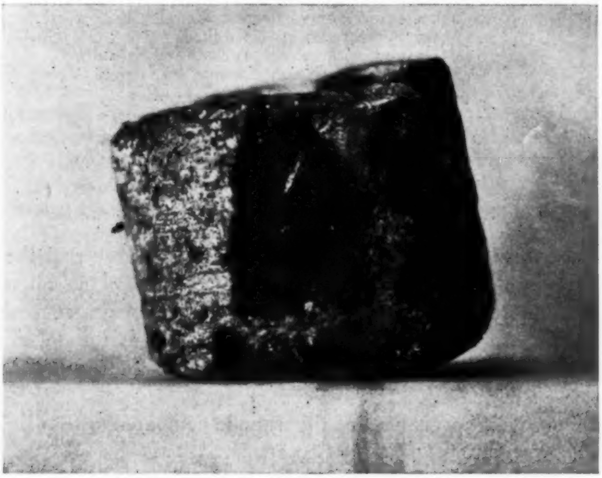

FIG. 1.—Lignite embedded in dolomite. The large piece of lignite in the center is intersected by veins of calcite.

[1]The three photographs accompanying this note were taken by F. H. Lahee, who also gave some valuable suggestions.

FIG. 2.—The dark angular fragments show the woody structure of the lignite.

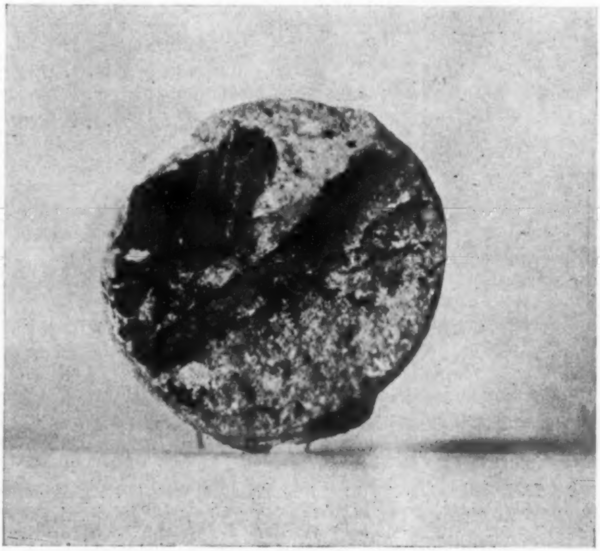

FIG. 3.—In the upper left part of the figure can be seen the woody structure of the lignite. The dark patch at the right contains fine calcite veins.

very shallow water, as is indicated by the presence of so much lignite. Not only was the water shallow, but land must have been near. The angularity of the fragments suggests that the lignite was formed *in situ* and not transported from some distant source. Whatever their mode of origin, it is evident that they did not replace sandstones, inasmuch as the silica content is negligible; nor is it likely that they were precipitated by the decay of organic matter, because the lignite is too well preserved.

The writer would like to know whether any similar occurrences have been noticed elsewhere, and also to have some discussion of this problem.

A. J. BAUERNSCHMIDT, JR.

DALLAS, TEXAS
February 25, 1930

DISCUSSION

INJUSTICE OF MISLEADING CITATIONS

In a reply to Dr. W. J. Mead in the February number of this *Bulletin*, Dr. Theodore A. Link referred to an article of mine[1] in such a way as to give the reader an erroneous idea of my work and opinions. In the present instance my article has been brought into a discussion with which it was not concerned, and the impression is given that I have overlooked points which in fact were explicitly covered. As a remonstrance against misleading citations, it seems to me desirable to place in juxtaposition Dr. Link's statement and my own of 20 years ago in the paper to which he has referred.

Dr. Link's statement.—"I actually believe that there *is* volume change and for that very reason the whole idea of the strain ellipsoid application to field problems in structural geology is not entirely sound. I have always felt this, and Professor Mead has now thoroughly convinced me of it. In connection with this same subject it is in place to call attention to the fact that Professor R. T. Chamberlin calculated the depth of the Appalachian folds on the basis of an unchanged or constant volume, and others have followed suit."[2]

The original statement for the Appalachians.—"It is also probable, on the whole, that in addition to the folding the lateral thrusts have caused a certain amount of mashing and compacting of the material of the beds. A few measurements upon the wax-and-plaster folds developed experimentally by Willis show that the decrease in the length of the layers due to mashing alone, varied from 1 up to 10 per cent of the original length. The total shortening of all kinds in the illustrations selected for measurement varied from about 15 per cent to somewhat more than 60 per cent. The variation in the amount of linear reduction due to mashing appears to correspond to differences in the character of the material used in the experiments. As a rule the softer the material in the layers the greater the degree of mashing; when more plaster and less wax and turpentine stiffened the layers, they were much less compacted. An average figure for the shortening of the layers due to mashing in these experiments by Willis would seem to lie in the neighborhood of 5 per cent. In the case of the Appalachians, however, the amount to be allowed for shortening due to mashing of the strata in addition to that resulting from the corrugation must be left largely to conjecture, but as the rock-formations are relatively much stiffer than the wax-and-plaster layers used in the experiments, it would seem likely that the figure for the mountains should be considerably less than 5 per cent.

"Tending to offset shortening due to the mashing of the rocks is the subsequent elongation of the strata arising from the opening of fissures, jointing,

[1] Rollin T. Chamberlin, "The Appalachian Folds of Central Pennsylvania," *Jour. Geol.*, Vol. 18 (1910), pp. 228-51.

[2] Theodore A. Link, "Author's Reply," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 241.

cementation by infiltration, and the penetration of igneous intrusions. Several former fissures near the junction of the Juniata with the Susquehanna have been rendered conspicuous by the intrusion of Mesozoic trappean magmas which have solidified within them. No attempt at any quantitative estimate of their importance in crustal shortening is made here. Whether the importance of these various secondary factors is material and whether, if ignored, the balance of their sum-total tends toward an overestimate, or an underestimate, of the true extent of the crustal shortening, is here left to the individual judgment of each geologist guided by his own experience and insight. The results reached later may have some reflex bearings on these points."[1]

Dr. Link in 1930 states his belief that there is change in volume in rock deformation. In 1910 I not only tacitly accepted change in volume *qualitatively*, as he has since done, but went further and attempted (in a crude fashion to be sure) to get some idea of its general order of magnitude.

This particular misrepresentation is, in itself, of no great importance, but I have a feeling that, for the good of the profession, matters of this sort should not be allowed to pass unchallenged. Perhaps, if more often called to account, authors will be less careless in their treatment of earlier writings.

ROLLIN T. CHAMBERLIN

UNIVERSITY OF CHICAGO
February 28, 1930

[1] Rollin T. Chamberlin, *Jour. Geol.*, Vol. 18 (1910), pp. 236-37.

REVIEWS AND NEW PUBLICATIONS

"Deep Wells of Iowa" (A Supplementary Report). *Iowa Geol. Survey Vol. 33*, Annual Report, 1927.

In 1912 the Iowa Geological Survey, in coöperation with the United States Geological Survey, published[1] a voluminous report of 994 pages on the underground water resources of the state, including in it logs of practically all the deep wells drilled up to that time. The present volume brings the record up to date.

Included are the records of about 150 wells drilled since 1912, chiefly in search of artesian water, although a few are designated as prospect holes for oil. Sample logs from most of these wells are given, as the Survey has been active in obtaining cuttings wherever this was possible. Correlations of strata are included, also interesting and valuable discussions of the geological relationships shown by the new wells. Of particular interest to Mid-Continent geologists are the recent wells drilled in western and southwestern Iowa, a number of which have penetrated the Ordovician. The deepest well in the state, that at Greenfield, Adair County, was completed in July, 1929, at a depth of 3,435 feet. Its log is given in detail, and shows the well to have been completed in the Jordan sandstone (Cambrian).

Included also is a structural contour map of the state, the contours being drawn on the top of the St. Peter sandstone. As is true of all the Iowa Survey reports, the printing and editing are excellent, and the typographical errors which so commonly creep into technical reports are conspicuously lacking.

J. V. Howell

300 North Fourth
Ponca City, Oklahoma
February 22, 1930

RECENT PUBLICATIONS

CALIFORNIA

"Shallow-Water Foraminifera from the Channel Islands of Southern California," by Joseph A. Cushman and William W. Valentine. *Contributions from the Department of Geology of Stanford University*, Vol. 1, No. 1 (February 28, 1930). Stanford University Press, Stanford University, Calif. 51 pp., 10 pls.

CANADA

"The Oil Fields of Alberta," by E. H. Cunningham Craig. *Oil Weekly* (Houston, Texas, February 28, 1930), pp. 70-71. See also *Petroleum Times* (London, February 15 and 22, 1930).

[1] "Underground Water Resources of Iowa," *Iowa Geol. Survey Vol. 21, U. S. Geol. Survey Water Supply Paper 293.*

CHINA

"Das älteste Bohrfeld der Welt in Szechuan (China)," by Arnold Heim. *Petrol. Zeits.* (Berlin, February 5, 1930), pp. 171-73, 9 illus.

GENERAL

Untersuchungsmethoden der Erdölindustrie, by H. Burstin. Julius Springer, Berlin, 1930. Research methods of the petroleum industry with particular reference to petroleum, benzine, paraffine, lubricating oil, and asphalt. 300 pp., 86 figs. Cloth-bound. Price, R M 22.

"Deepest Hole on Texas-Louisiana Gulf Coast, 8,150 Feet," by Richard A. Jones. *Oil Weekly* (Houston, Texas, February 28, 1930), pp. 28-29.

"Ordovician Trilobites of the Family Telephidae and Concerned Stratigraphic Correlations," by E. O. Ulrich. *Proc. U. S. Natl. Mus.*, Vol. 76, Art. 21, pp. 1-101, Pls. 1-8. (Washington, D. C., 1930.)

"Submarine Geology Opens Possibilities," by L. P. Stockman. *Oil and Gas Journal* (Tulsa, Oklahoma, March 13, 1930), p. 132, 1 illus.

GERMANY

"Paläogeographie und Erdölbildung, erlautert an den deutschen Erdölprovinzen," by Walter Kauenhowen. *Petrol. Zeits.* (Berlin, February 5, 1930), pp. 174-79, 7 illus., bibliography.

MOZAMBIQUE

"Die Geologie des Territoriums von Manica und Sofala (Mozambique) mit Rücksicht auf Oel und Steinkohlen," by J. C. S. van Soelen. *Internationale Zeitschrift für Bohrtechnik, Erdölbergbau und Geologie* (Vienna, February 15, 1930), pp. 31-36, 1 correlation chart, 1 map, 3 geologic cross sections.

ROUMANIA

"Remarques à propos du dernier travail de M. Krejci-Graf sur les gisements pétrolifères de la Roumanie," by Stanislas Zuber. *Revue Pétrolifère* (Paris, February 8, 1930), pp. 197-200.

TEXAS

"Over-Thrusting in Trans-Pecos Texas," by Charles Laurence Baker. *Pan-American Geologist* (Des Moines, Iowa, February, 1930), pp. 23-28, 1 illus.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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SAN ANTONIO SECTION OF A. A. P. G. ANNUAL MEETING AND FIELD TRIP

The annual technical session and field trip of the San Antonio Geological Society were held in Uvalde, Texas, on March 1 and 2, 1930. About 150 geologists, including many visitors from outside of the San Antonio district, attended the meeting. The entire day of Saturday, March 1, was given to the reading and discussion of technical papers, which covered a variety of important and timely subjects and aroused considerable interest. The program of the session follows.

1. "Chalcedony and Siliceous Deposits in Southwest Texas and Their Relation to Structure and Production," by Chas. H. Row.
2. "Geology of Bee, Live Oak, and Adjoining Counties," by I. K. Howeth and Kenneth Dale Owen.
3. "Thickening and Thinning of the Cretaceous and Tertiary Formations along the Balcones Fault of Southwest Texas," by L. F. McCollum and Joseph M. Dawson.
4. "Subsurface Conditions in Northeast Texas," by Don Danvers.
5. "Surface and Subsurface Faulting along the Bruner-Darst Creek Fault System," by Dilworth S. Hager.
6. "Production and Decline Curves of the Bruner and Darst Creek Fields," by R. F. Wheless. (Read by title.)
7. "Geology of Maverick, Zavalla, and Adjoining Counties," by F. M. Getzendaner.

8. "Geology of the White Point Gas Field," by Herschel H. Cooper.
9. "San Antonio Grass Roots Oil Field," by R. B. Swiger.
10. "Study of the Taylor Marl Formation in Travis County, Texas," by S. O. Burford.
11. "Evidence from Wells Penetrating the Coastal Plain in Alabama and Georgia on the Nature and Inclination of the Crystalline Basement," by D. R. Semmes. (Read by title.)

E. H. Sellards, of the Texas Bureau of Economic Geology, outlined briefly plans of the Bureau for the publication of additional stratigraphic information of use to economic geologists.

At the close of the technical session an hour was devoted to a business meeting, in which several questions relative to the American Association of Petroleum Geologists were discussed. At this time the following officers of the San Antonio Section of the A. A. P. G. were selected for the ensuing year: D. R. Semmes, president; Herschel H. Cooper, vice-president; Joseph M. Dawson, member of executive committee; Ed. W. Owen, secretary-treasurer. These officers, with Charles H. Row, the retiring president, constitute the new executive committee.

A barbecue was given Saturday evening by the citizens of Uvalde.

On Sunday, March 2, a field trip under the leadership of F. M. Getzendaner was made to several of the more interesting points in the Uvalde district. During the morning, exposures of bituminous members of the Escondido formation southwest of Uvalde were visited, and the large deposits of asphalt in the Anacacho limestone west of Uvalde were studied. J. B. Smythe, president of the Uvalde Rock Asphalt Company, conducted the party through the open pit mines of that company. The party was then taken southeast of Uvalde, where the relationship of several of the Cretaceous formations to the Mount Inge plug was observed.

On Sunday afternoon a 60-mile trip was taken through part of northern Zavalla County underlain by the lower members of the Tertiary. Later in the afternoon igneous plugs and associated Cretaceous beds in the vicinity of Knippa and Sabinal were studied and several interesting problems in regard to them were discussed.

The success of the field trip was largely due to the intimate knowledge of the area possessed by Mr. Getzendaner. The work of arranging the meeting was well done by a committee of the San Antonio Geological Society headed by Joseph M. Dawson. Thanks are due the citizens of Uvalde for their fine coöperation and hospitality.

Ed. W. Owen

San Antonio, Texas
March 5, 1930

AT HOME AND ABROAD

Kurt H. de Cousser, who recently completed a preliminary survey of the lower peninsula of Michigan for the White Star Refining Company of Detroit, has returned to Tulsa and is a member of the geological department of the Prairie Oil and Gas Company.

R. Schider, of Basle, Switzerland, has accepted the position of production manager for the Cia Mexicana de Petroleo "El Aguila." He may be addressed in care of the company at Apartado 150, Tampico, Mexico.

Marion H. Funk, formerly with the American Oil and Refining Company at Oklahoma City, has accepted a position on the geological staff of the Twin State Oil Company, with headquarters at Tulsa, Oklahoma.

W. O. George, who recently returned from geological work in Venezuela, has joined the geological department of the Twin State Oil Company, Tulsa.

E. F. Bullard is chief geologist for the Dixie Oil Company and L. G. Mosburg is assistant chief geologist, at Tulsa, Oklahoma.

Luther E. Kennedy, of the Douglas Oil Company, was working in the San Antonio district of Texas last month.

William Harvey is head of the land department and Avery Alcorn is head of the geological department of the new Midland, Texas, district office of the Wentz Oil Corporation.

Launcelot Owen is returning to England from Venezuela. En route, he is stopping in Colombia and Spain, but expects to be in London before the end of May. His address is Geological Department, Royal School of Mines, Prince Consort Road, London, S. W. 7, England.

At the regular meeting of the Tulsa Geological Society, Monday, February 17, W. E. Wrather gave an illustrated lecture on the geology of South Africa. At the meeting of the society on March 3, T. E. Weirich spoke on "The Simpson of Central Oklahoma," and Hugh McClellan gave a talk on "The Distribution of the Mississippian Sediments of Kansas."

B. K. N. Wyllie, the senior geologist of the A. P. O. Company's party which has been carrying on drilling at Papua for the Commonwealth Government of Australia, has returned to the United Kingdom.

John I. Moore, of San Angelo, Texas, who, for the past two years, has been in charge of the West Texas office of the Fuhrman Petroleum Corporation at San Angelo, Texas, severed his connection with that firm February 1, and has opened an office at 707 Western Reserve Life Building, San Angelo, Texas, to engage in independent work in West Texas.

D. H. THORNBURG, who for the past 2½ years has been employed in geological work for the Fuhrman Petroleum Corporation, severed his connection with that firm February 1 and has taken a position with the Adams Royalty Company to be in charge of their geological work in Texas and the Gulf states.

The Shawnee Geological Society recently elected new officers as follows: president, OSCAR HATCHER; vice-president, CLIFFORD BYRON; secretary-treasurer, S. W. HOLMES

STANLEY C. HEROLD, petroleum geologist of Los Angeles, California, has been appointed to serve as umpire in determining a fair and equitable division of the oil proceeds for the month of January, from the four producing wells on government permit acreage in the North dome, Kettleman Hills.

PAUL B. HUNTER has been transferred from the Muskegon, Michigan, district of the Shell Petroleum Corporation to their Houston, Texas, office.

J. H. PAGE, of the Oklahoma Natural Gas Corporation, formerly at Chanute, Kansas, is now in the Tulsa office of the company.

HALE B. SOYSTER has been appointed supervisor of the mineral-leasing division of the U. S. Geological Survey, with headquarters in Casper, Wyoming. Mr. SOYSTER has been for some time supervisor in the Mid-Continent division with headquarters at Muskogee, Oklahoma.

GEORGE C. BRANNER, state geologist of Arkansas, has been elected secretary of the State Geologists Association.

RICHARD L. TRIPLETT has been transferred from the Gypsy Oil Company, Mid-Continent subsidiary of the Gulf Oil Corporation at Tulsa, to the geological department of the Western Gulf Oil Company at Los Angeles, California.

HAROLD D. HERNDON, geologist, has been transferred from the San Angelo to the Fort Worth office of the Empire Gas and Fuel Company, and F. S. PROUT has been transferred to Tyler, Texas, for the same company.

In the annual membership list published in the March *Bulletin*, the asterisk denoting honorary membership in the Association was inadvertently omitted from the name of H. B. GOODRICH, of Tulsa, Oklahoma. Mr. Goodrich, who has been a member of the Association since 1918, was elected to honorary membership in August, 1929.

FRANK A. MORGAN, chief geologist of the Rio Grande Oil Company, Los Angeles, California, has an article on "Tideland Development in California," in the March 13 issue of the *Oil and Gas Journal*.

O. L. BRACE, vice-president and general manager of the Corana Petroleum Company of Corsicana, Texas, has moved his headquarters to Austin, Texas, where an office will be opened in the near future.

J. E. EATON, consulting geologist, of Los Angeles, California, has an article entitled "California May Yield Eight Billion," in the *Oil and Gas Journal* for March 13.

STANLEY C. HEROLD, petroleum geologist, Los Angeles, California, wrote on "Mechanics of a Production Curve," in the March 13 issue of the *Oil and Gas Journal.*

W. G. ARGABRITE has been connected with the Carter Oil Company at Tulsa, Oklahoma, since February, 1930, after having spent ten years in Venezuela and Colombia for the Standard Oil Company of New Jersey.

HOMER CHARLES, geologist for the Indian Territory Illuminating Oil Company, Bartlesville, Oklahoma, and Miss MARJORIE SMITH, of Chanute, Kansas, were married recently.

FRED B. ELY and R. A. MCGOVERN, 11 Broadway, New York City, have organized Mines and Petroleum Engineers, Inc.

SIDNEY PAIGE, consulting geologist, of 25 Broadway, New York City, has returned from a professional trip to Venezuela.

W. C. MENDENHALL, of the U. S. Geological Survey, Washington, has been appointed general secretary of the Sixteenth International Geological Congress, to be held in Washington in 1932.

ANDREW N. MACKENZIE is in charge of the geological work of the Venezuela Petroleum Company in Venezuela. His address is 206 Calle Paez, Valencia.

FRED H. KAY, of the Pan-American Petroleum and Transport Company, of New York City, is in Asia on professional business.

J. ELMER THOMAS, of Fort Worth, Texas, was appointed chairman on March 10, and JOSEPH E. POGUE, of New York City, was appointed secretary of a committee on petroleum economy to make a complete and unprejudiced analysis of the status of petroleum demand. The appointment was made by Secretary of the Interior Wilbur.

V. E. COTTINGHAM, San Angelo, Texas, and his bride, formerly Miss ROSE VORPAHL, have returned from a honeymoon trip to Florida and Cuba.

J. P. LEE of The Pure Oil Company has been transferred from Texas to Jackson, Mississippi.

B. COLEMAN RENICK has resigned from the Shell Petroleum Corporation at Dallas to enter consulting practice. His address is the Lamar Hotel, Houston, Texas.

H. T. BECKWITH, formerly of Bartlesville, Oklahoma, has moved to San Bernardino, California, where he is engaged in consulting geology.

ROBIN WILLIS will teach for one quarter at Stanford University, taking the place of ELIOT BLACKWELDER, who is absent on leave. At the completion of his work Mr. Willis will go to Calgary, Canada, in the employ of the Nordon Corporation.

C. H. BEHRE has resigned from the University of Cincinnati to join the geological department of Northwestern University, Evanston, Illinois.

H. W. McClellan is in charge of micropaleontologic work for the Burke-Greis Oil Company, Tulsa.

Francis X. Bostick, of the Southern Crude Oil Purchasing Company, has moved to Tyler, Texas.

J. O. Haas has moved from Pechelbronn, France, to Ouegoa, Nouvelle-Caledonie (New Caledonia).

The annual meeting of the Division of Geology and Geography of the National Research Council will be held in Washington, D. C., May 3.

Henry A. Ley, of Tulsa, has been estimating gas reserves at Amarillo.

W. H. Twenhofel, of the University of Wisconsin, lectured in April at Wichita, Oklahoma City, Tulsa, and Fort Worth on "Origin and Constitution of Limestones and Related Rocks."

H. H. McKee, of Brokaw, Garner, Dixon, and McKee of New York City, has been in Amarillo.

M. J. Munn, of Tulsa, is in charge of the Little Rock, Arkansas, office of the Cosden Oil Company.

David White published in *Science News-Letter* (March 8, 1930), "Leaves Older than Grand Canyon Found. Fossil Ferns Tell of Weather in Permian Age." The plant remains were found in the Hermit shale.

F. G. Clapp has returned from Paris and his address is now: Tudor Arms, Pondfield Road, W., Bronxville, New York.

Karl Krejci, who has been working in Campina, Roumania, has gone to Canton, China, to teach paleontology in the Sun Yat Sen University.

Walter E. Hopper, of Shreveport, Louisiana, is president of the Southern States Company, Inc. The company specializes in tubing high-pressure oil and gas wells.

C. G. Willis is president of the Nordon Company, of Delaware, the American subsidiary of the Nordon Corporation, Ltd., of Canada. Ben Hake and Robert B. Moran are associated with him at Los Angeles, and Robin Willis represents the company at Midland, Texas.

Scott Turner, director of the U. S. Bureau of Mines, has been elected vice-president and director of the American Institute of Mining and Metallurgical Engineers.

K. C. Heald published a summary of a research project of the American Petroleum Institute entitled, "Determination of Geothermal Gradients in Oil Fields on Anticlinal Structure" in the Institute *Bulletin*, Vol. 11 (1930), No. 1 (D. & P. E. *Bulletin 204*).

L. E. Trout is head of the land and geological departments of Julian Oil and Royalty Corporation of Oklahoma City.

M. W. LAKE, formerly resident geologist for the Richfield Oil Company, at Taft, California, has been appointed superintendent of the Midway-Sunset and Lost Hills fields.

W. VAN HOLST PELLEKAAN, vice-president of the Shell Petroleum Corporation at St. Louis, Missouri, left in March for a business trip to The Hague.

A. A. LANGWORTHY, division geologist for The Pure Oil Company in Tulsa, has recovered from an extended illness.

CHESTER NARAMORE, of New York City, returned from Germany in February.

T. K. HARNSBERGER, chief geologist of the Shell Petroleum Corporation at Tulsa, has returned to the office after a long illness.

J. A. MACDONELL, of Lima, Ohio, delivered a series of lectures at Johns Hopkins University on the geology of South Africa.

FRANK B. NOTESTEIN, who represents The Texas Company in South America, spent his vacation in New York City.

FRANK A. MORGAN, chief geologist of the Rio Grande Oil Company, and DREXLER DANA, geologist and petroleum engineer for that company in the San Joaquin Valley, published in the *Oil Bulletin* (Los Angeles, March, 1930) a paper entitled, "Maricopa Flat—a New Field in an Old Area." The structure of the field is a monocline (homocline). "The oil accumulation here is believed to be due, first, to the ready access of this up-dip area to the broad gathering area of the San Joaquin Valley; second, to a recognized tendency of the Maricopa shale series to contain interfingering sand members near its shoreward limits; and, third, to the peculiar conditions of monocline erosion and unconformable overlap which are particularly favorable for local accumulation."

DOLLIE RADLER, administrative geologist for the Amerada Petroleum Corporation at Tulsa, Oklahoma, and a member of the class of 1920 of the University of Oklahoma, has been elected to membership in the Alpha of Oklahoma chapter of Phi Beta Kappa, on the basis of distinction attained since graduation.

FOREST R. REES has resigned as chief geologist of the Petroleum Royalties Company and is now chief geologist for the Peters Petroleum Corporation at Tulsa, Oklahoma.

F. B. PLUMMER and HELEN SLEWES PLUMMER, of Austin, Texas, lectured on "Geology of Petroleum" and "Foraminifera," respectively, at Northwestern University during March and April.

The School of Petroleum Engineering, H. C. GEORGE, director, University of Oklahoma, Norman, Oklahoma, offers "A Summer Field Course in the Petroleum Industry," June 4 to August 1, 1930. The course will consist of a study of operating methods in the Greater Seminole area and in the new Oklahoma City oil field. The number of accepted applications is limited to 100. No applications will be accepted after May 10.

N. L. Thomas, of The Pure Oil Company, Fort Worth, lectured on "Laboratory Geology," March 14, at Baylor University, Waco, Texas.

Albert S. Clinkscales is affiliated with the Kessler Petroleum Corporation, of Oklahoma City, as geologist and head of the land department, supervising the drilling activities of the Kessler Corporation. He is a director of the corporation.

R. C. Beckstrom, in charge of the school of petroleum engineering at Tulsa University, gave an illustrated lecture on "Conditions of the Oil Industry of Russia" before the Tulsa Geological Society, March 17.

Louis Roark announces the opening of an office as consulting geologist and operator of The Oil Flow Indicator (L. E. Trout & Co.), 435 Philcade Building, Tulsa, Oklahoma.

A. J. Freie, formerly with the Indian Territory Illuminating Oil Company, is now geologist for the Trinidad Oil Fields Operating Company, at San Fernando, Trinidad, B. W. I.

The Institute Geologico y Minero de España, Cristobal Bordiu 12, Madrid, has published the Monograph of the XIV International Geological Congress on the world's resources of potash. This monograph in two large volumes costs 60 pesetas (about $7.50) postpaid. Monographs on iron resources were published by the Swedish Congress, on coal resources by the Canadian Congress, and on pyrite deposits by the Spanish Congress.

The XIII International Geological Congress, held at Brussels in 1922, published a colored tectonic map of Eurasia by Emile Argand, scale 1:25,000,000, size 17x21 inches, price $1.00 postpaid from the Secretary of the Congress, Palais du Cinquantenaire, Brussels. The text describing the map was published in the Comptes-Rendus: fasc. 1 (Liege, 1924), pp. 171-372.

In our March issue we stated that *Economic Geology* had become the official bulletin of the Society of Economic Geologists, with Alan Mara Bateman of Yale University as editor and W. S. Bayley of the University of Illinois as business manager. We have since learned that this is a somewhat misleading statement inasmuch as *Economic Geology* has not been taken over by the Society but simply serves as a bulletin for the Society and retains its established independent status, with its columns open to any contributor throughout the world regardless of whether he is a member of any society. Subscriptions, as heretofore, are available to anyone.

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of J. P. D. Hull, Business Manager.

This service is available both to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with Mr. Hull, especially concerning positions available to active and associate members.

PROFESSIONAL DIRECTORY